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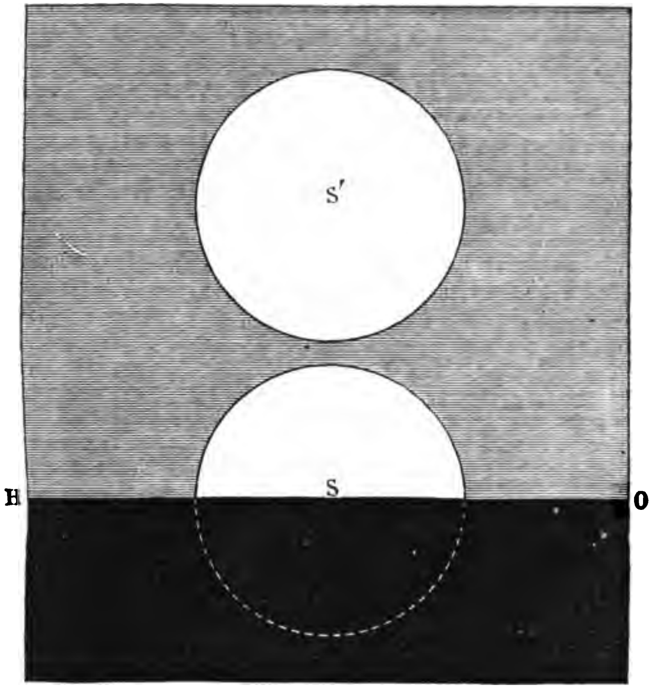

COMMON THINGS.

THE ALMANACK.

CHAPTER I.

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1. Of all books the Almanack is the most indispensable. So constant is the need for it, that, unlike other books, it is not deposited on the shelf, but lies ready at hand on the table. This general and constant utility, which ought to have exempted it from fiscal restriction, was precisely the circumstance which marked it out for the fatal visitation of the Stamp Office, and raised, thereby, for many years a barrier against its improvement. The moment of its emancipation from the Chancellor of the Exchequer having, however, at length arrived, it was indefinitely multiplied, assumed a thousand shapes, was offered at prices suiting all pockets, in dresses suiting all tastes, with accessories and appendages adapted to the exigencies of all avocations, and was sometimes even given gratuitously as a convenient vehicle for the commercial announcements which accompanied it.

One might imagine that a book thus so universally necessary would be as universally understood; nevertheless it may be fairly questioned whether one in ten thousand of those who daily consult it have any clear or definite notions of the import of even those parts of it to which they refer, and it is beyond all doubt that of many other parts they have no notion whatever. It has, therefore, appeared to us that some explanatory notice of its contents will not be unacceptable to our numerous readers.

Almanack, or Almanach, is an Arabic term derived from the word manah, *to reckon*.

2. In the almanack the Calendar holds a prominent place, so prominent indeed that the terms are sometimes used interchangeably. Nevertheless, *Calendar* has a more special and limited application. The first day of the Roman months was called calends, and hence a table showing the successive days of each month, and indicating the festivals and anniversaries civil or religious, which fell upon them, came to be called The Calendar.

It has been already explained in our Tract on "Time," that the word month has various senses. It may mean the moon's periodic time, that is, the time it takes to make a complete revolution round the earth. It also expresses the time which elapses between two successive new moons. This is called a Lunar month, and sometimes a Synodic month. In law, four weeks are taken to be a month. The year consists of twelve unequal parts, which are called Calendar months. These are the months which have received the names with which every one is familiar.

3. The almanack is a year-book, and is published before the commencement of the year whose date it bears, and to which its contents are related.

The contents of the almanack are, therefore, necessarily predictions.

The prediction of fixed anniversaries, whether civil, religious or natural, requires no calculation, since they fall from year to year upon the same days. The recurrence of many celestial phenomena, which are of great popular and civil interest, varies from year to year; and some religious and civil festivals and observances which are conventionally regulated by them, are subject to a like variation, and the prediction of the days of their recurrence depends on similar calculations.

4. The people of all classes in all countries seeing the precision with which so many and such various phenomena were foretold, were not slow to manifest a craving after like predictions of events of quite another order; and almanack makers were not—and are not even now—wanting who pander to this demand. We have, accordingly, almanacks including predictions of the vicissitudes of weather, of the occurrence of great political events, and in short of everything which can be imagined to gratify the spurious appetite of the credulous. It must be admitted, to the discredit of certain of our public bodies, that they have long condescended to traffic in this sort of charlatanism, and to derive a revenue from thus imposing on public credulity. If precedent, however, can be admitted as any extenuation of this practice, they may claim to have sinned in good company, for Arago relates that he had the following anecdote from Lagrange.

"The Berlin Academy, so celebrated for the vastness of physical discoveries and researches which were consigned to its transactions, formerly derived its chief revenue from the circulation of its almanack. This publication from an early period included a mass of pretended predictions of meteorological phenomena and political events, like those which figure in some of our own almanacks of much more recent date. Ashamed of sanctioning the publication of such absurdities, the Academy, upon the proposition of one of its leading members, resolved at one time upon suppressing them and supplying their place with more rational and useful matter.

"The immediate consequence of the reform was the almost total suspension of the revenues of the Academy by the great decrease of the sale of the almanack, so that the learned body was literally starved into compliance with the public demand, and compelled to reissue annually a collection of pretended predictions which were a subject of ridicule to those who invented and compiled them."

A similar circumstance occurred with respect to Moore's Almanack, of which the sale was reduced in amount by the omission of the column which assigned the effects produced by the signs of the zodiac on human members.

Another of the early almanacks which owed its immense circulation to the same cause, was one published at Liège, under the name of Matthew Laensberg, a canon of that city. "When we speculate on human credulity," observes Arago, speaking of this almanack, "we may be confident of success. It is in vain that, from year to year, the events are in flat contradiction to the predictions. The public does not the less resort to the famous almanack, so true is the saying of La Fontaine:—

> L'homme est de glace aux vérités,
> Il est de feu pour le mensonge."

Arago relates a curious accidental coincidence which gave the Laensberg Almanack prodigiously increased vogue. In the Almanack for 1774, there appeared a prediction that "one of the most favoured ladies would play her last part in the month of April." Now, it so happened, that in the month of April, Louis XV. was attacked at Versailles with the small-pox, and the notorious Madame Dubarry was expelled from the palace.*

5. The religious anniversaries indicated in the calendar, consisting principally of the days consecrated by the Church to the commemoration of saints and martyrs, necessarily vary in different Christian countries, according to the varying forms of the faith. The personages recognised as saints in the Roman Church are at least six times as numerous as the days of the year; and although the Greek Church does not recognise exactly the same collection, their list is equally abundant. A selection has been made by each branch of the Church, and the name of a saint or martyr is appropriated to each of the three hundred and sixty-five days; and to such an extreme is this carried, that a saint is even given to the intercalary day in bissextile years. Thus, in the Roman Church, the intercalary day is appropriated to St. Damien, and in the Greek branch to St. Cassian.

The identification of the days of the year severally with the names of canonised personages, will explain the familiar allusions to the "Saints of the Calendar."

In Protestant States, and more especially in England, this long list of saints is greatly curtailed, all those whose canonisation took place subsequently to the imputed corruption of the Church being rejected. In Catholic countries, however, the names regis-

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* For a more recent specimen of the effect of such an accidental coincidence occurring among ourselves, see our Tract on "Weather Prognostics."

tered in the calendar have become so closely interwoven with the national manners and customs, that it is unlikely that any reformation should efface them. It is the general practice to celebrate the anniversary of each individual, not, as with us, upon that of his or her birth, but upon the day consecrated to the memory of the saint whose name he or she bears. By this usage each day in the calendar becomes as it were the peculiar property of certain individuals, and to efface the saints would be practically to rob all the world of their festivals. In certain times and among certain people such a measure would excite an insurrection.

6. The very first date indicated in the Almanack, that from which it takes its title, and which is marked upon its back, the number designating the year, may require some brief explanation. What is meant, for example, by the year 1855? What is its beginning? what its end? From what point of departure are its units reckoned? 1855 since when? These are questions to which the answers are not quite so obvious as they may seem.

7. During the first five centuries after the birth of Christ, the Christians, comparatively few in number, and scattered among different and distant peoples, used in their records no other mode of expressing dates than those which prevailed among the nations of which they severally formed a part. In 532 A.D., when their numbers and importance had augmented, Dionysius Exiguus, a monk of Scythian birth, proposed that all Christians should adopt the epoch of the birth of Christ as their point of departure in counting time and in the expression of dates. This rendered necessary an investigation into the question of the date of that event. Dionysius made historical researches, the result of which assigned the birth of Christ to the 25th day of December, in the 753rd year from the foundation of Rome.

It might have been expected, therefore, that the first Christian year would commence on that day, and that its anniversary would be the first day of each succeeding year. It was, however, found inconvenient to change the commencement of the year, and it was resolved to adhere to that of the Roman year theretofore used by the Church—that is, to the 1st January, and that the first year of the Christian era should be the 754th year from the foundation of Rome. According to the mode of reckoning finally adopted, therefore, the year 1 A.D. was that which commenced at the moment of the midnight between the 31st December in the 753rd, and the 1st January in the 754th year of Rome.

The uncertainty which must necessarily attend the exact date of an event so remote as the birth of Christ, occurring moreover in an obscure corner of a remote Roman colony, and though attended with future consequences so important, invested with no circumstances which could lead to its having been recorded in the public annals, does not at all affect chronology; since whatever may have been the actual day of Christ's birth, that which connects the Christian with the ancient chronology is the first day of the year 754 of Rome.

To convert any year A.D. into the corresponding year of Rome, it is only necessary therefore to add 753 to it. Thus the year 1 A.D. was the year 754 of Rome, the year 20 A.D. was the year 773 of Rome, and so on.

It will be observed that the first year of the Christian era is not, as might be imagined, that of the birth of Christ, but the following year. It is the year in which, according to the researches of Dionysius Exiguus, Christ completed his first year.

8. Since, according to the Christian chronology, time is counted thus prospectively forward from the birth of Christ, the *year after* that event being taken as the first year of the series, it might by analogy be presumed that in counting time retrospectively the *year before* the same event would be taken as the first year of the backward series. Thus while the year after that of the birth of Christ is 1 A.D., the year before that of the birth of Christ would be the year 1 B.C., and consequently that the year itself in which Christ was born would be either 0 A.D. or 0 B.C. indifferently. By such a mode of expressing dates, the interval between any day in any year A.D., and the corresponding day in another year B.C., would be found by adding together the numbers expressing the years. Thus the interval between 1st July, 1 A.D., and 1st July, 0 B.C., was 1 year; the interval between 1st July, 1 A.D., and 1st July, 1 B.C., was 2 years; the interval between 1st July, 15 A.D. and 1st July, 14 B.C. was 29 years, and so on.

And this is, accordingly, the method of expressing dates which astronomers use. It is, however, unfortunately, not that adopted by historians and chronologists. According to these the year 753 of Rome, in which Christ is supposed to have been born, is the year 1 B.C., and consequently all their dates B.C. exceed the corresponding dates of astronomers by 1. Thus the year which astronomers call 500 B.C., historians call 501 B.C.

To find, therefore, the interval between any day in a year A.D. and the corresponding day in any year B.C. when the historical dates are used, it will be necessary to add together the two dates and subtract 1 from their sum.

9. Historical events are often referred to by stating that they occurred in such or such a century. Now one might well suppose that there could arise no obscurity or confusion in the use of such a term, yet it is notorious that after the year 1800, questions were

constantly raised in society as to whether such or such a day or month belonged to the eighteenth century or to the nineteenth.

The first day and the starting point or zero of the Christian chronological scale was the midnight with which the 1st January, 1 A.D. commenced. This was the moment, therefore, at which the *first century* began, and it ended evidently when, dating from that moment, 100 complete years had elapsed. The first century, therefore, terminated and the second began at the midnight between the 31st December, 100 A.D. and the 1st January, 101 A.D. In like manner the second century terminated and the third began at the midnight between the 31st December, 200 A.D., and the 1st January, 201 A.D. It is evident, therefore, that the entire year 100 A.D. belonged to the first century, and the entire year 200 A.D. to the second century; and, in the same manner, it follows that the entire year 1800 A.D. belonged to the eighteenth century. The eighteenth century therefore commmenced with the 1st January, 1701 A.D., and terminated with the 31st December, 1800 A.D., both these days belonging to that century. In like manner the first day of the nineteenth century was 1st Jan., 1801 A.D., and its last day will be 31st December, 1900 A.D.

10. One of the series of dates predicted in the almanack are those which mark the commencement of the seasons. The winter terminates and the spring commences at the moment of the vernal equinox; the spring terminates and the summer commences at the moment of the summer solstice; the summer terminates and the autumn commences at the moment of the autumnal equinox, and the autumn terminates and the winter commences at the moment of the winter solstice. The conditions which determine the equinoxes and solstices have been explained in our Tract on "Time."

Owing to a certain small variation in the rate at which the sun moves annually round the firmament—the cause of which has been explained in the same Tract—the seasons are not equal in length. The following are their lengths respectively:—

	D.	H.	M.
Spring	92	20	50
Summer	93	14	7
Autumn	89	17	49
Winter	89	1	2
	365	5	48

If the civil year, that is the year of the almanack, were identical with the equinoctial year, the seasons would commence respectively always upon the same days of the year. But although the civil year in the long run does not vary to any perceptible extent from the equinoctial year, this coincidence is not continual and results from the compensation produced by the device of bissextile or leap years, for a full explanation of the origin and purpose of which, see our Tract on "Time." By this expedient the civil years form a quadrennial cycle, consisting of three years of 365 days, and one year of 366 days. Now it will be easy to see that the consequence of this is, that the commencement of spring oscillates forward and backward alternately, being for the first three years of the cycle continually $5^h\ 48^m$ later, and in the last year $18^h\ 12^m$ earlier. On this account the first day of spring sometimes falls upon the 20th and sometimes on the 21st March.

As the length of the seasons respectively remains the same, it follows that the commencement of them severally is subject to a like variation. The commencement of summer oscillates between the 21st and 22nd June, that of autumn between the 22nd and 23rd September, and that of winter between the 21st and 22nd December.

To make this more evident let us take for example the quadrennial cycle, which commenced with the year 1853. The commencement of spring in the year 1853 was at $4^h\ 40^m$ in the afternoon of the 20th March. The year 1853, having only 365 days, while the interval between the two successive equinoxes is $365^d\ 5^h\ 48^m$, it follows that the commencement of spring in 1854 was $5^h\ 48^m$ later, and consequently took place on the 20th March, at $10^h\ 28^m$ in the evening. In the same manner, 1855 having only 365 days, the next commencement of spring is again $5^h\ 48^m$ later, and consequently takes place at 16 minutes past 4 o'clock in the morning of the 21st March. The following year, 1856, is, however, leap year, and has 366 days, while the interval between the equinoxes being only $365^d\ 5^h\ 48^m$, is $18^h\ 12^m$ less, and consequently the commencement of spring will be $18^h\ 12^m$ earlier in 1856 than it was in 1855, and, therefore, will take place at 4 minutes past 10 o'clock in the morning of the 20th March.

Thus the commencement of spring alternately advances and retrogrades; but the Julian cycle of four years, modified by the Gregorian cycle of 400 years, produces such a compensation, that for many thousands of years it cannot be earlier than the 20th or later than the 21st March, and the variation of the commencement of the other seasons is subject to similar limits.*

11. It will be evident, therefore, that although the year, in respect to its length, has a relation to the course of the seasons, it has no such relation in respect to its beginning and end. It

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* See Tract on "Time."

might have been supposed that, as all civilised people have concurred in adopting the course of the seasons as the great unit of time, they would have also fixed the limits of these units as they succeed each other, by making them correspond with the natural limits of the seasons. It is a very remarkable fact, nevertheless, that, although various beginnings and endings of the year have been adopted at different ages and in different nations, not one that we know of was determined by the natural limits of the seasons.

12. Some religious observances, such, for example, as Christmas, the Assumption, the Annunciation, always return upon the same days of the same month. Others, such, for example, as Easter, Trinity Sunday, Whitsunday, Corpus Christi, return on different days in each successive year, and are hence called MOVEABLE FEASTS.

To assign from year to year the dates of these moveable feasts is one of the chief religious uses of the calendar.

The principal of the moveable feasts, and that upon which the dates of all the others depend, is Easter,* or the festival of the Resurrection.

13. The Resurrection took place at or near the full of the moon which followed the equinox. This was also the time when the Jews were accustomed to celebrate their festival of the Passover. The celebration of that feast was regulated not only by the sun, but also by the moon, and as the period of the lunar phases is not commensurable with that of the seasons, the Passover was necessarily a moveable feast, in reference to an equinoctial year. The Christian festival was celebrated at the Paschal full moon, because its origin was connected with the *time* of the Passover. Many of the early Christians held Easter to be the Jewish Passover continued as a Christian rite, and celebrated it on the day of the Passover instead of the Sunday after. The Nicene Council put a stop to this notion and practice; and means were taken at the reformation of the calendar to prevent the Christian festival from falling actually upon the same day as that of the Jewish Passover.

14. It is a great error, though a very common one, to suppose that

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* The Saxons had a goddess to whom they sacrificed in the month of April, called *Eoster* (known in Greek as *Astarte*, and in the Hebrew as *Ashtoreth*). To this goddess, according to Bede, they sacrificed in April, which they called *Eoster-monath*. Some have thought that the word *East* in Saxon referred to rising, and that the point of the compass thus gets its name from the rising of the sun, and the festival from the rising of the Saviour. But the former is the most probable derivation. Christian rites and usages sometimes acquired the names of their heathen predecessors.

the date of the festival of Easter has a strict dependence upon the periodical phases of the moon. As our knowledge of astronomy has been for ages progressive, and as the tables of the lunar motions more especially have been subject to continual improvement, being rendered more and more exactly in accordance with the phenomena as science has advanced, it would follow that, if Easter were strictly regulated by the moon, the ecclesiastical authorities, from whom the calendar has always emanated, would be dependent on the astronomers of the time being for the means of predicting from year to year the days to be appointed for the celebration of Easter; inasmuch as a rule prescribed by the astronomers of the 14th century would fail before the improved knowledge of those of the 15th; as the rule prescribed by the latter would be rendered erroneous by the still more exact knowledge obtained by those of the 16th, 17th, 18th, and 19th.

Now, any person who will refer to the prefatory matter prefixed to the Book of Common Prayer, will see that the means of predicting the days upon which the Feast of the Resurrection will fall for centuries to come, are given entirely irrespective of the contingent discoveries of astronomers, and of the possible errors which might have prevailed in times past as to the lunar motions.

That approximate coincidence between the epoch of the celebration of the Resurrection and the astronomical dates of the vernal equinox and the full moon was designed, is undoubtedly true, and that the technical rules laid down for calculating from year to year the day of the celebration of the Resurrection, does lead to a certain rough correspondence with the lunar phases, may be admitted. But the determination of Easter-day has no necessary dependence on, and is not meant to be defined by, the actual lunar phenomena as seen in the heavens.

15. According to the rule established by the Roman branch of the Catholic Church, and which has been followed by the Church of England, the day of the celebration of the Feast of the Resurrection is determined, according to the explanation of the English Church, in the following manner:—

Find the day of the first full moon which occurs on or after the day of the spring equinox. The festival of Easter will be celebrated on the Sunday next following that day.

16. Now it is most necessary to the clear comprehension of the calendar, and for the prevention of numerous errors into which even well-informed persons frequently fall, to observe emphatically that not one of the principal terms used in this rule is to be understood in its usual and obvious meaning. The "spring equinox" does not mean the real spring equinox of the astronomers, the "moon" does not mean the moon which shines in the

firmament, nor does "full" moon mean a moon with a complete circular phase.

It often happens, accordingly, that the day appointed in the calendar for Easter Sunday is altogether different from the day on which that festival would fall, if the terms of the rule were used in their usual sense, and in such cases we find the newspapers filled with indignant imputations of error in the calendar, and visiting the public wrath upon those under whose direction it was compiled and computed.

17. We have shown that the commencement of spring, or what is the same, the moment of the spring equinox, is subject to variation in relation to the civil year, falling sometimes on the 20th and sometimes on the 21st March. The spring equinox of the calendar is, however, an imaginary equinox, which is supposed never to vary from the 21st March. Thus, even when the real equinox falls on the 20th March, the fictitious equinox of the calendar, by reference to which Easter is determined, still falls upon the 21st March.

18. The term "moon" in the rule signifies also a fictitious object, created or imagined expressly to suit the purposes of the calendar. Nor is the adoption of such a fiction, where it serves convenient purposes, unwarranted or unusual. Astronomers themselves have found their computations of the celestial phenomena materially facilitated and simplified by creating fictitious suns, moons, and planets, to which imaginary motions are imputed; and it may, therefore, be fairly contended that the creation of a fictitious moon for ecclesiastical purposes is not less justifiable.

The ecclesiastical moon is an object whose motions are governed by certain numbers, called the "golden numbers" and the "epacts." These numbers have a relation to the periodical changes of the real moon, in virtue of which the place of the ecclesiastical moon can never vary from that of the real moon beyond a certain limit. Thus the full of the one may differ by as much as two days from the full of the other, but not more.

A "full" moon, whether real or fictitious, is that which is presented at the middle of the interval between two successive new moons. Thus, if this interval be 29½ days, the full moon will take place in 14¾ times 24 hours after the moment of new moon. Now this is not the sense in which "full" moon is to be understood in the rule. To define exactly the sense of "full" moon in the rule, it will be necessary first to explain how the "age" of the moon is expressed in the language of the calendar.

19. The day upon which the moon is in conjunction with the sun, or, what is the same, upon which new moon takes place, is, properly speaking, shared between the old and the new moons.

If, for example, the conjunction take place at 3 o'clock in the afternoon, the interval of 15 hours since midnight belongs to the old, and the remaining 9 hours, until the next midnight, to the new moon. It is the custom, nevertheless, to call this the "first day of the new moon," and not the "last day of the old moon." Consequently, the "second day of the moon" is the day upon which it completes the first twenty-four hours of its age and commences the second twenty-four hours, and so on.

It may be objected that this mode of expressing the moon's age would lead to certain absurd consequences. It may happen, for example, that the moment of new moon may be only a second before midnight, in which case only *one second* of the entire day will belong to the new moon, and the day will, nevertheless, be called the "first of the moon."

Notwithstanding this, the first day of the moon is the day upon which the conjunction takes place, or the day upon which the new moon commences, no matter how late in the day, no matter how near its close the moment of such commencement may happen to be.

20. By the day of "full" moon in the rule, is then to be understood, not, as might be expected, the day upon which the middle of the interval between new moon and new moon falls, but the 14th day of the (ecclesiastical) moon's age; that is, according to what has been just explained, the day upon which that moon terminates its 13th and begins its 14th, twenty-four hours.

21. Thus it appears that the day of the full moon, by which the date of Easter-day is fixed, is not only not that of the full moon visible in the heavens, nor of the fictitious moon imagined by astronomers to define the average place of the real moon, but it is not even the day on which the fictitious ecclesiastical moon itself is full. In fine, the use of the term "full" in the rule given in the Book of Common Prayer is altogether incorrect, whatever sense may be attached to the term moon, and the rule ought to be expressed as follows:—

Find the day on or next after the 21*st March upon which the ecclesiastical moon attains the* 14*th day of its age. The Sunday which next follows that day will be Easter-day.*

Now, provided that the ecclesiastical moon be understood, this rule (after the explanation given above of the mode of expressing the age of the moon) is clear and definite.

It will be observed, that, according to the terms of the rule, if the 14th day be Sunday, Easter-day must be the following Sunday; but the 21st of March may itself be the 14th day.

It remains, therefore, only to explain the conditions which define the fictitious object which we have here called the ECCLESIASTICAL MOON.

22. Let it be remembered that the astronomical year consists of 365 days, 5 hours, 48 minutes, and 48 seconds, and that a lunar month varies in length from about 29¼ days to 29¾ days, its average length being exactly 29 days, 12 hours, 44 minutes, and 3 seconds.

It will appear from these numbers that 19 astronomical years consist of about

D.	H.	M.	S.
6939	14	27	12,

while 235 average lunar months consist of about

D.	H.	M.	S.
6939	16	31	45.

It appears, therefore, that 235 average lunar months exceed 19 astronomical years by only 2 hours, 4 minutes, and 33 seconds.

It follows from this, that if the course of time be resolved into a succession of periods, or *cycles*, of 19 astronomical years, the same phases of the moon which are presented in any year of one cycle will be reproduced in the corresponding year of the next cycle, on the same days, but 2 hours, 4 minutes, and 33 seconds later. If, therefore, the dates of the phases, those of the new moons for example, in each successive year of any one such cycle be ascertained, either by immediate observation or by calculation, their dates in the successive years of the next cycle will be on the same days, but 2 hours, 4 minutes, and 33 seconds later.

If, therefore, time were counted by astronomical years, and if the period of the lunar changes were always equal to the average lunar month, the days of new moons of any one cycle of 19 years being ascertained, the days of the new moons of every succeeding, and of every preceding cycle, would be known.

23. But time is not counted by astronomical years, and the period of the lunar phases is not always the same, and therefore this reproduction of the series of lunar phases, or corresponding days, will not take place.

Unlike the astronomical year, the civil year is not constantly of the same length. It consists, as has been already explained, sometimes of 365, and sometimes of 366 days. Neither is a cycle of 19 successive civil years always of the same length. Such a cycle contains sometimes only five, and sometimes four, leap years, and consists, therefore, sometimes of 6940, and sometimes of 6939 days. It, therefore, sometimes exceeds a cycle of 19 astronomical years by nearly a quarter of a day, and sometimes falls short of such a cycle by more than three-quarters of a day. If four successive cycles of 19 civil years be taken, three of them will exceed one astronomical year by something less than a quarter of a day, and the fourth will fall short of an astronomical year by something more than three-quarters of a day. The total length of the four successive cycles of 19 civil years will be as nearly as possible equal to four cycles of 19 astronomical years.

Thus it is evident that the civil year, though variable in length, oscillates alternately on one side and the other of the astronomical year; and, in like manner, the cycle of 19 civil years, which is also variable by one day, oscillates at each side of the cycle of 19 astronomical years. The civil year and the civil cycle are alternately overtaking and overtaken by the astronomical year and cycle, and their average lengths are respectively equal in the long run to the average length of the latter.

In like manner, the lunar month is subject to a certain limited variation, so that the phases of the real moon are alternately overtaking and overtaken by those of the average moon.

24. Now let us imagine a fictitious moon to move round the heavens in the path of the real moon, but with such a motion that its periodical phases shall take place in exact accordance with the civil years, and with the cycles of 19 civil years, in the same manner as the phases of the real moon recur in the succession of astronomical years, and in the cycles of 19 astronomical years. Such a fictitious moon is then the ecclesiastical moon, and is the moon whose phases are predicted in the calendar.

It will be evident from all that has been explained, that this ecclesiastical moon will alternately pursue, overtake, and outstrip the real moon, and be pursued, overtaken, and outstripped by it; that they will thus make together their successive revolutions of the heavens, and that they will never part company, nor either outstrip or fall behind the other beyond a certain distance, which is limited by the extent of the departure of the civil from the astronomical year, and by that of the real from the average lunar month.

25. For the purposes of the calendar, therefore, the course of time is supposed to consist of a succession of cycles of 19 civil years, and it has been agreed that each such cycle shall commence with a year the first day of which shall be the last day of the moon's age, or, what is the same, the day on which the age of the succeeding moon is 0.

The number which marks the place of any year in the cycle to which it belongs is called the GOLDEN NUMBER of the year. Thus when we say that the Golden Number of the year 1855 is 13, we mean that the year 1855 is the 13th year of the cycle to which it belongs, and it may be thence inferred that the first year of the cycle was 1843.

26. The age of the ecclesiastical moon on the first day of the first year of the cycle being known, its age upon the first day of

each succeeding year of the cycle may be determined. The number which expresses the age of the moon on the first day of any year of the cycle is called the EPACT of that year.

The series of EPACTS corresponding to the GOLDEN Numbers of the years of a cycle are given in the following table:—

Golden Number .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Epact . .	0	11	22	3	14	25	6	17	28	9	20	1	12	23	4	15	26	7	18

27. The age of the ecclesiastical moon on the first day of any year being thus known by the EPACT, which, as well as the GOLDEN NUMBER, is given in the Almanack, the age of the moon for every day of the same year can be ascertained, and by this means the date of Easter, according to the conditions of the rule, may be determined.

28. To show the application of the Golden Numbers and Epacts, and the departure of the ecclesiastical moon from the real moon, let us take for example the year 1855. The Golden Number being 13, the Epact, as appears by the above table, will be 12, and consequently, on the 1st of January the ecclesiastical moon will be in its 12th day. Its first day was, therefore, the 21st of December. Now, by referring to the lunar tables given in the almanacks, it will be found that the age of the real moon at the midnight which commenced the 1st of January, was 12 days 2¼ hours, and consequently the real moon was new on the evening of the 19th of December, at three-quarters of an hour past 9 o'clock.

It appears, therefore, that in this case there is a difference of two days between the real and ecclesiastical moons.

29. It is the ecclesiastical moon which alone figures in the calendar, and by the phases of which the date of Easter is governed: let us now see within what limits the variation of that festival, and consequently of all the other moveable feasts which depend on it, are confined.

30. It appears by the rule, rightly interpreted, that Easter will be the first Sunday after the 14th day of the ecclesiastical moon which occurs next after the 20th of March.

The earliest date of Easter compatible with these conditions would be when the 14th day of the ecclesiastical moon would fall on the 21st of March, and that the 21st of March itself should fall on a Saturday. In that case the following day, that is, the 22nd of March, would be Easter Day. Earlier than this the festival of Easter cannot fall, consistently with the rule laid down by the Church.

This contingency actually occurred in the year 1818. Its occurrence is, however, as may be imagined, very rare. Thus for three centuries, before 1818, it only happened three times, viz., in 1598, in 1693, and in 1761, and it will not happen again until 2285.

31. That Easter should be celebrated on the latest day which is permitted by the rule, it would be necessary that the 14th day of the ecclesiastical moon should be as late as possible after the 20th March, and that it should fall upon Sunday. To be as late as possible, it would be necessary that the 20th March should be itself the 14th of the moon. In that case the 14th of the next moon would fall upon the 18th April, which being by the supposition Sunday, Easter-day will by the rule be the following Sunday, that is the 25th April. Later than this Easter cannot fall, consistently with the rule laid down by the Church.

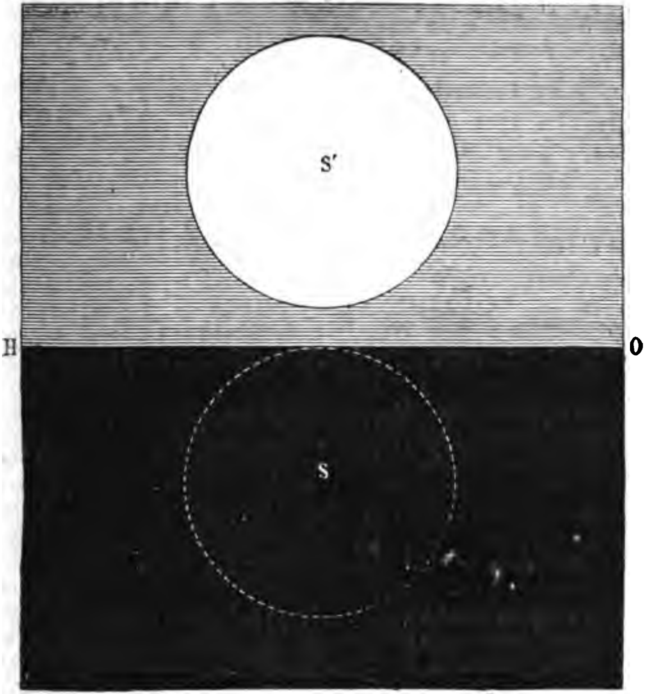
This contingency last occurred in 1734, and will next happen in 1886. It occurred in 1666 and will occur in 1943, in 2038, in 2190, &c.

Thus it appears that Easter-day may fall upon any of the 35 days, which are included between the 21st March and the 26th April, but that it cannot be earlier than the 22nd March, nor later than the 25th April.

32. The moon, the phases of which determine Easter, is called the Paschal Moon, and it is most important to bear in recollection that it is not the real visible moon of the heavens, but is the fictitious or imaginary moon called the Ecclesiastical Moon.

As the 14th day of the paschal moon cannot be earlier than the 21st March, nor later than the 18th April, it follows that the first day of that moon cannot be earlier than the 8th March, nor later than the 5th April.

Fig. 2.



COMMON THINGS.

THE ALMANACK.

CHAPTER II.

33. Paschal moon sometimes gives a different Easter from real moon.—34. Occasion of public controversies.—35. Professor De Morgan points out error in Act of Parliament.—36. Other moveable Feasts.—37. Extract from De Morgan's Book of Almanacks.—38. Whit-Sunday.—39. The Indiction.—40. Solar Cycle.—41. To find the year of the current solar cycle.—42. Dominical or Sunday Letter.—43. How affected by Leap-year.—44. Sunday Letter of the year 1 A.D.—45. To find Sunday Letter for any year.—46. Eras.—47. Julian Period.—48. Its commencement determined.—49. Its use in chronology.—50. Contents of the Calendar.—51. Aspect of the Heavens.—52. Times of rising and

setting of celestial bodies.—53. Distortion produced by the atmosphere.—54. Other effects.—55. True and apparent sunrise.—56. The sun seen before it rises.—57. Conventional meaning of the terms sunrise and sunset.—58. Refraction.—59. The Equinoxes —60. Day and night rarely of the same length.—61. How modified by refraction.

33. SINCE the dates of the corresponding phases of the real and ecclesiastical moons never differ one from the other by more than two days, and generally by still less, it happens most commonly that the 14th of the paschal moon and the full of the real moon fall in the same week, and in all such cases the date of Easter-day would be the same, whether it be determined by the one moon or the other. But they may and sometimes do fall in different weeks. Thus the full of the real moon may fall on a Friday or Saturday, while the 14th of the paschal moon falls on Sunday or Monday. In that case the date of Easter determined by the paschal moon will be a week later than if it were determined by the real moon.

On the other hand the 14th of the paschal moon may fall on Friday or Saturday, while the full of the real moon falls on Sunday or Monday. In that case the date of Easter, as determined by the paschal moon, would be a week earlier than its date determined by the real moon.

34. Whenever this discordance arises between the dates of Easter, as it would be determined if the real moon presided over it, and as it is determined by the ecclesiastical moon, the public press teems with diatribes either against the astronomers for misdirection of the computers of the almanacs, or against the computers for running counter to the lunar tables of the astronomers. As examples of this may be mentioned the year 1798, in which by the dictates of the real moon Easter should have fallen on the 1st April, but the ecclesiastical moon postponed it to the 8th; the year 1818, in which the real moon would have assigned it to the 29th March, but the ecclesiastical moon threw it back to the 22nd March, and the year 1845, in which the ecclesiastical moon placed Easter on the 23rd March, while the real moon would have postponed it to the 30th.

35. It was on the last mentioned occasion that the questions raised, and the disputes which prevailed, produced two remarkable essays on the subject of the Calendar and its history, by Professor De Morgan, which were published in the "Companion to the British Almanack for the years 1845 and 1846." In these articles were for the first time exposed some glaring errors committed by the British Legislature in the Act of Parliament (24 Geo. II., cap. 25, A.D. 1751), which at the time of the change of style

regulated the calendar, and supplied those rules and explanations which are still prefixed to the Book of Common Prayer of the Established Church. Professor De Morgan showed that the Legislature committed the error of taking the real moon of the heavens, as that by the phases of which Easter was to be determined, although the authorities from which they borrowed their rules, and which it was their intention to follow, most expressly disclaimed the celestial moon, and even showed the objections against taking it for the determination of the date of Easter. But the blunders did not end here. The professor further showed that not only the British Parliament, but astronomers themselves, and even many authors who had written expressly on the calendar, were altogether ignorant of the fact that it was not the day of the full, even of the ecclesiastical moon, but the 14th day of that moon's age, by which Easter was to be determined. Nevertheless, as the terms of the rule for determining Easter, properly understood, were correct, although the explanations and commentaries appended to them by the Legislature were erroneous; and as it was the evident intention of the Act to adopt the same method of determining the date of Easter as was used in the Roman Catholic Church; the computers of the almanacks were not misled by the wrong explanations, but continued to fix Easter as it was fixed in the Roman Church, and as in fact it was intended to be fixed in the Church of England.

36. The conditions which determine from year to year the date of Easter being well understood, the dates of other moveable feasts, all of which have fixed relations to Easter, will be determined. Some of these come before, others follow, Easter. As Easter, therefore, advances or recedes in date, it pushes forward the latter, and draws after it the former.

37. The following short explanation of the moveable feasts of the Church, and their dependance on Easter, which we borrow from Professor De Morgan's "Book of Almanacks," cannot be improved:—

"In the English nomenclature Easter Sunday has always the *six* Sundays in Lent immediately preceding, and the *five* Sundays after Easter immediately following. Of these the nearest to Easter before and after are *Palm* Sunday and *Low* Sunday; the farthest before and after are *Quadragesima* (first in Lent), and *Rogation* Sunday (fifth after Easter). Preceding all these are, in reverse order, *Quinquagesima*, *Sexagesima*, *Septuagesima:* and following them in direct order, are the Sunday after *Ascension* (Holy Thursday, Thursday five weeks after Easter), *Whit* Sunday and *Trinity* Sunday. So that Easter Sunday, as it takes its course through the almanacks, draws after it, as it were, *nine* Sundays, and pushes *eight* before it, all at fixed denominations. Looking farther back, every Sunday preceding Septuagesima, but not preceding the fixed day of Epiphany (Jan. 6th) is named as of *Epiphany* or after *Epiphany:* the least number of Sundays after Epiphany is one, the greatest number six. Looking farther forwards, all the Sundays following Trinity are named as *after* Trinity, in succession, until we arrive at the nearest Sunday (be it before or after) to St. Andrew's Day (Nov. 30th), which is the first Sunday in *Advent.* The least number of Sundays after Trinity is twenty-two; the greatest, twenty-seven. From thence, up to Christmas Day, exclusive, the Sundays are named as in *Advent*, and from Christmas Day to Epiphany, exclusive, they are named as Christmas Day, or as the first or second Sunday after Christmas."

38. The name WHITSUNDAY, or WHITE-SUNDAY, given to the festival of the Pentecost, is taken from an old custom of candidates for baptism, or for the first communion, wearing white dresses on the occasion, a custom still observed by females in Catholic countries.

39. In all almanacks a certain number is found connected with the year, called the INDICTION.

The Indiction is a period of fifteen years, having no reference to any religious observance or commemoration, nor any correspondence with astronomical phenomena. It was a conventional division of time, which was first established in the Roman empire and its dependencies, in the time of Constantine, and the origin of the name is unknown. It has been conjectured, that Constantine, desiring to discontinue the Pagan methods of reckoning time by Olympiads, which were periods of four years, and finding besides a longer division more convenient, established the Indiction.

The Indiction, unlike the periods marked by the golden number and the epact, had no relation to religion, but was used in the courts of law and in the fiscal administration of the empire by Constantine and his successors, and was continued under the Popes.

The point of departure of the Indictions was finally fixed by Gregory VII. to be the first day of the year 313, and calculating back from that, it would follow that the first year of the Christian era was the fourth year of the current Indiction. If then it be desired to find the numerical order of any proposed year since Christ in the current Indiction, it is only necessary to add 3 to it, and divide by 15, the remainder will be the sought number, and will be the Indiction of the proposed year. Thus, to find the Indiction of the year 1855, we add 3, which gives 1858, and dividing by 15 we find the remainder 13, which is the Indiction.

40. A common year of 365 days consists of 52 weeks and 1 day. It follows, therefore, that such a year is always followed by one which begins one day later in the week. If seven such years followed each other in uninterrupted succession, their first days would be the seven successive days of the week.

But a leap year consists of 52 weeks and 2 days; therefore, the first day of the year which succeeds it will be two days later in the week than that of the leap year. Since in seven successive years there *must* be one, and *may* be two leap years, it follows that the first days of the years included in such a period will not include all the days of the week.

To find the interval which must elapse between two years, each day of which will fall upon the same day of the week, it will be evidently necessary to find a number of years which will consist of an exact number of weeks. If there were no leap years, this number would evidently be 7, since the odd day which is contained in each year, seven times repeated, would make up a week, so that 7 years would consist of 4 times 52 weeks and 1 week, that is 209 weeks exactly. But the recurrence of a year of 366 days every fourth year prevents this.

Four years consist of 208 weeks and 5 days. It will be necessary, therefore, to find how often this interval must be repeated to make a complete number of weeks; or, what is the same, how often five days must be repeated to make a complete number of weeks. Now this is evidently 7 times, which will make up 5 complete weeks. If 4 years, therefore, be repeated 7 times, we shall obtain a number of years which will be also an exact number of weeks. But this number of years is 28, and it consists of 7 times 208 weeks, together with five weeks, making in all 1461 weeks.

After every successive period of 28 years, therefore, the same days of the year will fall upon the same days of the week.

This period of 28 years is called the SOLAR CYCLE.

41. The first year of the Christian era being taken to be the tenth of the current solar cycle, it follows, that to find the numerical order of any proposed year in the current solar cycle, we must add 9 to the year, and divide by 28; the remainder, if any, will be the order of the year. If there be no remainder, the year will be the last, or the 28th of the current cycle. Thus, for example, to find the order of the year 1855 in the solar cycle, adding 9, we have 1864, and dividing by 28, we obtain the remainder 16, showing that 1855 is the 16th year of the cycle, and the first year of the present cycle was therefore 1840.

42. The DOMINICAL, or SUNDAY LETTER, which appears prefixed to the calendar, is an expedient by which the days of the week, which fall upon the successive days of any proposed year, past or future, may be determined. This expedient has a close relation with the solar cycle just explained.

If the general calendar usually prefixed to the Book of Common Prayer of the Established Church be referred to, it will be seen, that in the column which follows that of the numbers expressing the days of the month, the first seven letters of the Alphabet, A, B, C, D, E, F, and G, are annexed, and are continually repeated, for every successive series of seven days to the end of the year; the intercalary day of the 29th of February, in the case of a leap year, being, however, past over, and the letter which succeeds that annexed to 28th February being annexed to 1st March, as it would if the year were a common year of 365 days.

Now, if these seven letters be supposed to express the seven successive days of the week upon which the first seven days of the year fall, they will express equally the days of the week upon which all the succeeding days of the year fall, when it is a common year of 365 days, which we shall for the present suppose it to be, and the same letter throughout the year will everywhere express the same day of the week. Thus, if the 1st January fall on Sunday, the letter A, which is annexed to the 1st January, being also annexed to every seventh successive day to the end of the year, all these days must be Sundays.

In the same manner, the letter B being annexed to the 2nd January, that day being Monday, the same letter B will be found after every seventh succeeding day to the end of the year, and, therefore, all such days having B annexed will be Mondays.

It will be evident that like inferences will be applicable to the days marked by the other letters, and that similar consequences would follow if the 1st January were supposed to fall upon any other day.

Whatever, therefore, be the day from the 1st to 7th January, inclusive, upon which Sunday may happen to fall, the letter found annexed to that day will be found annexed to all the succeeding Sundays in the year; and consequently, if the day of the first seven on which the Sunday falls be known, the letter annexed to it will make known without further computation all the Sundays in the year.

This letter has therefore been called the DOMINICAL, or SUNDAY LETTER.

43. But we have here supposed the year to be a common year of 365 days. If it be a leap year, the case will be different. In that case the letter which is annexed to the 1st March, will

express a day of the week one day later than that which it expressed before the 29th February, and the same will consequently be true of all the other letters. Thus, if the 22nd February, to which D is annexed, were Monday, all the other days, from 1st January to 28th February, to which D is annexed, would also be Mondays, and consequently the 28th February, to which C is annexed, must be Sunday, and therefore the 29th, to which no letter is annexed, must be Monday, and therefore 1st March, to which D is annexed, must be Tuesday, and all the succeeding days, to the end of the year, to which D is annexed, must be Tuesdays. Thus, in a leap year, if D express Mondays before the 29th February, it will express Tuesdays after that day, and, in general, each letter after the 29th February, will express the day of the week which succeeds that which is expressed before the 29th February.

It follows, therefore, that the Sunday letter in a leap year after the 29th February, is the Saturday letter before it, and is, consequently, the letter of the alphabet which precedes the Sunday letter at the beginning of the year. Thus, if the Sunday letter before 29th February be C, the Sunday letter after it will be B, if D it will be C, and so on. If the Sunday letter before 29th February be A, it will be G after it.

A leap year, therefore, has two Sunday letters, the first applicable to the part before, and the other to the part after, the 29th February.

44. It has been supposed that the birth of Christ took place on the Sabbath of the Jews, and consequently on the day now called Saturday. Since 1st January is the seventh succeeding day, it follows that the first day of the first year of the Christian era was Saturday, and consequently the Sunday letter of the year 1 A.D. was B.

45. Since a common year consists of 52 weeks and one day, it follows that the first and last day of such a year will fall upon the same day of the week, and that the first seven days of the next year will fall upon the week days which immediately succeed those upon which they fell in the preceding year. This will supply an easy rule, by which, when the Sunday letter of any year is known, those of all succeeding years may be at once found without calculation.

Let us suppose that the 1st January, in a certain year, is Sunday. The Sunday letter will then be A for that year. The year being supposed to be a common year, its last day will also be Sunday, and therefore the first day of the next year will be Monday, and the seventh, Sunday. The Sunday letter of that year will then be G.

I like manner it may be shown that the Sunday letter of the next, being a common year, will be F, and in fine, in general, the Sunday letter of a year which succeeds a common year will be the letter which precedes the Sunday letter of the year before.

The same will be true when a leap year is succeeded by a common year, only in that case the Sunday letter of the latter will be that which precedes the Sunday letter of that part of the leap year which follows the 29th February.

These observations will be illustrated by the following table of Sunday letters of the years 1840 to 1860:—

Years.	Sunday Letters.	Years.	Sunday Letters.	Years.	Sunday Letters.
1840	E D	1847	C	1854	A
1841	C	1848	B A	1855	G
1842	B	1849	G	1856	F E
1843	A	1850	F	1857	D
1844	G F	1851	E	1858	C
1845	E	1852	D C	1859	B
1846	D	1853	B	1860	A G

46. It is known to every one that different nations count their years and refer their historical events to different epochs, or ERAS,* as the points of departure have been called.

47. As may be easily conceived, much confusion arises from this cause. To compare together historical dates which refer to different eras, it is necessary to make a calculation based upon the interval between the eras to which the dates are severally related. It has therefore been considered to be a matter of great convenience to historical students in general to have some fixed era of common reference, to which dates referred to other eras may be reduced, so as to form a common standard of historical and chronological time, as the first day of the year does in the case of civil time applied to shorter intervals. A period has been accordingly agreed upon for this purpose, derived from the combination of the three cycles, the Metonic, the Solar, and the In-

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* Etymologists differ as to the origin of this word. The Latin *æra* is by some derived from the plural of *æs*, brass or money; in the plural signifying also counters. Others derive it from the Greek; others from the Arabic; and according to others, it is composed merely from the initials of the Latin sentence *Ab exordio regni Augusti*, "from the beginning of the reign of Augustus."

diction, which have just been explained. To find a certain number of years, which is at the same time an exact multiple of each of these cycles, we have only to multiply together the number of years in each of them. Thus, if we multiply 19 by 15, we shall obtain 285 years, which consists of exactly 15 cycles of Meton and 19 Indictions. Again, if this last number, 285, be multiplied by 28, we shall obtain 7980 years, which consists of exactly 285 solar cycles, or of 420 Metonic cycles, or, in fine, of 532 Indictions.

This interval of 7980 years was proposed as a common historical and chronological period, by the celebrated historian Joseph Scaliger, who gave it the name of the JULIAN PERIOD.

48. For the purposes of history and chronology, it was not, however, enough to suggest such a cycle. It was necessary to discover its natural and proper starting-point or era. Supposing that we are now at some point in such a current cycle, what is that point?—or, which is the same thing, what was the first year of the period?

Since the period proposed consists of an exact number of cycles of Meton, an exact number of Indictions, and an exact number of solar cycles, it is evident that its natural and proper commencement must be the year which was at the same time the first of a Metonic cycle, the first of a solar cycle, and the first of an Indiction. Now, as we know the first years respectively of each of these current cycles, it is only necessary to count each of the three back into past times until we find a year which is at once the first year of each of the three. That year will then be the first year of the current Julian period.

This is precisely what Scaliger did. He took, for example, the first year of the then current Metonic cycle, and counting back from 19 years to 19 years, made a table of the first years of each cycle, expressed with reference to the Christian era. He then took in like manner the first year of the current Indiction, and by counting back from 15 years to 15 years, made a like table of the dates. He then took the first year of the current solar cycle, and made a similar table. In these tables he sought and found the year before Christ which was a first year of the Metonic cycle, a first year of the Indiction, and a first year of the solar cycle. This was the year 4713 B.C.

He therefore fixed the commencement of the Julian period at the year 4713 B.C., or, to be still more precise, on the 1st of January in that year, at the moment of mean noon for the meridian of Alexandria, that being the place at which the observations of Ptolemy were made, and to which the tables of that celebrated astronomer and observer were related.

49. Ideler, in his "Handbuch der Mathematischen und Technischen Chronologie," in reference to this convention of Scaliger, says that by its employment light and order were for the first time let in upon the obscurity and confusion in which ancient history and chronology were involved.

Since the year of the birth of Christ was then the 4713th of the Julian period, the order of any later year of the Christian era in the Julian period will be found by adding 4713 to the year. Thus, for example, the year 1855 is the 1855 + 4713 = 6568th year of the current Julian period.

To find the order of any year before Christ in the Julian period, it will be only necessary to subtract the year from the order of the year 1 A.D. in the Julian period, that is, from 4714. Thus, knowing that the date of the invention of the Metonic cycle was 432 B.C., its date in the current Julian period was

$$4714 - 432 = 4282.$$

50. The Calendar, properly so called, is constructed differently in different almanacks. In most, if not all, it gives for each day the times at which the sun and moon rise and set, and the time at which the latter passes the meridian; the moon's age, and the sun's declination. We shall briefly notice each of these useful indications.

51. The hours at which the heavenly bodies rise and set upon the same day at different places are different. This arises either from the different places being at different distances from the pole of the earth—that is, having different latitudes, or being on different meridians of the earth, that is, having different longitudes. In either case the heavens, as seen from them, being viewed from different stations, will be seen under different aspects. Celestial objects, which will be invisible from one place, will be visible from the other. The heavens may be considered as a panorama, and the earth as a vast circular gallery or series of galleries in its centre, to which a slow motion of revolution is imparted, so as to exhibit to every spectator every part of the great canvas of the heavens in succession. The parts of the heavens seen by spectators, differently situated in these central galleries, will obviously be different. An object which will be just coming into the view of some,—that is, rising,—will be in full front of others,—that is, on their meridian,—and will be disappearing from others, that is setting. Spectators placed in the upper galleries, that is, in northern latitudes, will look down upon objects to which spectators in the lower galleries, that is, in southern latitudes, will look up, and which spectators in the middle galleries, that is, between the tropics, will see directly before them.

52. Now all these circumstances must be taken into account if we desire to predict by calculation the portion of the heavenly panorama which will be presented to the view of spectators at any given place, at any given time, and the objects, whether they be sun, moon, or planets, which may happen to be upon that portion of the panorama. And this is precisely what astronomers do when they compute those tables of the rising and setting, and the meridional transits of these objects. Without going into the technical details upon which such computations are based, it will be evident that if the position of a place upon the earth's surface be given, the aspect under which the heavens will be seen from that place, shifting from hour to hour, can be ascertained beforehand, and the positions in which all objects upon it will be seen at any given hour, minute, and second, or the hour, minute, and second at which they will have any proposed position on the visible hemisphere, can be certainly and exactly predicted.

These, then, speaking generally, are the principles upon which the numbers given in those columns of the calendar to which we have just referred have been computed.

53. We see this vast spectacle, however, not immediately, but by the intervention of a medium which produces upon it certain optical effects. Our station is at the bottom of an ocean of transparent fluid, about fifty miles deep. This fluid is called the atmosphere, and it is by looking upwards through it that we see the heavens. Such a medium, however clear and translucent it may be, has always a certain distorting effect upon the objects seen beyond it. It is as though we saw the heavens through a thick sheet of glass, the external part of which is convex, and the internal concave. The celestial objects are by this, therefore, more or less distorted in form, and disturbed in their position in relation to the horizon. It is true that owing to the air being a very light and attenuated fluid, and especially so at great heights, this distortion and derangement are so inconsiderable, that except in particular cases they can only be perceived by astronomical observers, and by them only with the aid of good instruments, by which very small differences of direction and position can be ascertained.

Nevertheless, there are cases in which this curious atmospheric influence is palpable to the sight. Every one who has observed the fiery orb of the sun, or that of the full moon just before setting or soon after rising, when they are seen through a thick mass of air at low altitudes, will have noticed that they do not appear round as they ought to be, but oval, the longer diameter of the oval being horizontal. Now this is a distortion of their form produced by the mass of air through which they are seen.

54. Another effect of transparent media, and the air among the rest, is to change the apparent direction of objects seen through them. Every one can verify this by looking at distant objects through pieces of glass having curved or angular surfaces. They are never seen in their true directions.

The effect produced by the air is to make all objects appear at greater altitudes than they really have, or than those at which they would be seen if the air had not been interposed. The effect of this is greater at low than at high altitudes. When an object is very near the horizon, which it is just before it sets or just after it rises, its apparent altitude is greater than its true altitude by something more than half a degree: now half a degree is equal to the apparent diameter of the sun or moon.

If an object, therefore, were in such a position, that without the interposition of the atmosphere it would be seen exactly on the horizon, as when it rises or sets, the atmosphere would cause it to appear at more than half a degree above the horizon.

In the same manner, if an object were half a degree below the horizon, and therefore having already set or not yet risen, and being consequently invisible, it would by the effect of the atmosphere be seen above the horizon, and would therefore be visible.

It is evident, therefore, that the atmosphere makes all objects appear to rise sooner and to set later than they would rise or set if the atmosphere were absent; and consequently, in calculating the rising and setting of the sun and moon, this must be taken into account.

55. It may be asked whether it be really true, as would appear from what has been just explained, that the air enables us to see the sun before it has risen, and after it has set? There can be no doubt that such is the case, and that at the moment indicated in the almanack, as that of sunrise or sunset, the sun is really below the horizon and not upon it. These circumstances, which are not only interesting in themselves, but affect in a very considerable degree the calculations of the almanack, will be rendered more easily intelligible by reference to figs. 1 and 2.

The horizon is represented by the line H O, the dark part being below, and the shaded part above it. The moment of sunset or sunrise is, properly speaking, that at which the centre of the sun's disc is seen upon the horizon H O, and, when consequently, the horizon would pass across the middle of the disc, one half of which would be above it, and therefore visible, and the other half below it, and therefore invisible, as shown at S, fig. 1.

The moment at which the centre of the sun would be seen at S, fig. 1, in the absence of the atmosphere, is called the moment of TRUE SUNRISE or SUNSET, and for a long time this was the time of sunrise and sunset given in the almanacks.

The moment at which the centre of the sun's disc, seen as it is through the atmosphere, is at S, fig. 1, is called the moment of APPARENT SUNRISE or SUNSET, and is the time now given in the almanacks.

56. As we have already stated, the apparent altitude of objects on or very near the horizon is greater than their true altitude by more than half a degree. But the apparent diameter of the sun being itself about half a degree, it follows that the sun is elevated by the optical effect of the air to an altitude greater than its real altitude by more than its own apparent diameter.

If then we take a point S′, at a height above S, fig. 1, equal to that by which the atmosphere augments the apparent altitude, this height, S′ S, will be greater than the apparent diameter of the sun, and when the real centre of the sun's disc is at S, it will appear to be at S′, and the disc of the sun, instead of being seen at S, the horizon dividing it into two equal parts, will, in fact, be seen at S′, not only quite clear of the horizon, but with its lowest part more than a quarter of a degree above the horizon.

Let us take another case which is still more curious. Let the true position of the sun's disc, that is, the position it would have if there were no atmosphere, be that shown at S, in fig. 2, being that which it has the moment before it begins to rise, or the moment after it has completely set. In this position the disc just touches the horizon, and the depression of the centre of the disc below the horizon is a quarter of a degree. Now what is the effect of the atmosphere?—to make the centre of the disc appear to be more than half a degree higher, and consequently more than a quarter of a degree above the horizon. The disc, therefore, which is really altogether below the horizon, is in this case seen in fact altogether above it as shown at S′, fig. 2.

57. The terms SUNRISE and SUNSET are commonly used, as indeed most other terms are, in a loose and vague sense. The sun may be said to be in the act of rising from the moment at which the highest point of its disc begins to be seen until its lowest point just touches the horizon; that is, from the moment it has the position S, fig. 3, until it has attained the position S′. In the same manner it may be said to be in the act of setting from the moment it has the position S′, until it has sunk to the position S.

But in order to give a definite signification to the terms SUNRISE and SUNSET, it has been agreed to apply them to the moment at which the centre of the sun's disc is on the horizon, as it is shown at S, fig. 1. Thus the conventional moment of sunrise and sunset is intermediate between the actual beginning and end of the sun's appearance or disappearance.

All the observations which have been here made respecting the rising and setting of the sun are equally applicable to the rising and setting of the moon, the apparent diameter of which is equal to that of the sun.

The interval between the moment at which the sun or moon begins to rise or set, and that at which it has completely risen or set, varies in different places and at different seasons, but is generally something more than two minutes.

58. The optical property of the air, by which the effects above described are produced, is called refraction; and the displacement which is produced in the position of an object is called its refraction.

The refraction is greater or less according as the altitude is greater or less, and disappears altogether when the object is in the zenith, that is, when it is directly above our heads.

The effect, therefore, of refraction is to make the sun rise earlier and set later than it would if no atmosphere existed. The days are thus at all seasons rendered longer, and the nights shorter, than they would be if the earth were not surrounded by an atmosphere; and as the effect of refraction retards the setting and accelerates the rising by about two minutes, it increases the length of the day, and decreases that of the night by about four minutes; this, however, is subject to variation depending on the latitude of the place and the season of the year.

59. The equinoxes, as commonly understood, are those days in March and September on which the intervals of light and darkness are equal, the sun rising and setting at 6 o'clock.

Now any one may convince himself by reference to the columns of sunrise and sunset in an almanack that no such days ever exist.

Yet the very name of equinox is taken from the supposition of equal day and night. How then is the equinox to be understood, and from whence has it derived its name?

It may perhaps be supposed that although there be no case of day and night absolutely equal, the equinoxes may be those days in March and September in which the day and night are least unequal.

But if the columns of sunrise and sunset be examined in any almanack, it will be found that the day upon which the intervals of light and darkness are least unequal, precedes the day of the equinox in March and follows it in September, by one or two days.

This is so contrary to the commonly received notions that the point will require some explanation.

The sun's disc makes a circuit of the heavens in a year. Its position from March to September is such as to render the days longer, and from September to March such as to render them shorter than the nights.

At a certain moment on some day in each of these months, the sun's disc has such a position that if it were to remain stationary in that position, and if there were no atmosphere, sunrise and sunset would take place exactly at 6 o'clock, A.M. and P.M., and consequently the days and nights would be precisely equal, each being twelve hours.

The moment at which the sun's disc has this position, is that of the equinox.

60. Before the equinox in March, the position of the sun has a tendency to render the nights longer, and after it to render them shorter than the days.

Before the equinox in September, its position has a tendency to render the days longer, and after it shorter than the nights.

If on the day of the March equinox, the equinox take place exactly at noon, the sun will have a tendency for the preceding twelve hours to render the night longer, and, for the succeeding twelve hours, shorter than the day. In that case, these effects will compensate each other, and if there were no atmosphere the day and night would be equal. But in this case sunrise and sunset would take place not at six o'clock, but a little later. The tendency of the sun for the twelve hours before noon being to render the nights longer than the days, the sun would not rise till after six, and its tendency during the twelve hours of the noon being to render the day longer than the night, the sun would not set until after six.

If the equinox of March take place in the forenoon, the tendency of the sun in the interval since the preceding midnight being to render the nights longer than the days, and its tendency in the longer interval until the next midnight being to render the days longer than the nights, the latter tendency will prevail, and the day would be longer than the night.

If the equinox of March take place in the afternoon, the contrary effects will ensue for like reasons, and the night would be longer than the day.

Similar observations will be applicable to the equinox of September, but with opposite results. If the equinox take place in the forenoon, the night will be longer than the day, and if in the afternoon, the day will be longer than the night.

It must not be forgotten, however, that these conclusions are such as would follow only on the supposition that the effect of the atmosphere is excluded.

Thus it will be seen that, putting aside the consideration of atmospheric refraction, day and night could never be precisely equal, except in the rare case in which the equinox takes place at the moment of noon.

61. Let us now consider how these phenomena are modified by atmospheric refraction, which, as has been shown, increases the length of the day and decreases that of the night; and it must be observed that their effect is much more considerable than any which can arise from the moment of the equinox occurring either in the forenoon or the afternoon.

On the day of the March equinox, whether day and night be equal or unequal so far as depends on the position of the sun, the effect of refraction will be to cause the length of the day to be greater than that of the night, since its effect greatly predominates over any which the sun's change of position could produce.

On the preceding days, refraction has the same tendency, but then the tendency of the sun's position to render the night longer than the day is more considerable, and will be such as to balance or predominate over the effect of refraction either one or two days before the equinox. The consequence is, that the day upon which the intervals of light and darkness are either exactly equal or least unequal, will be either one or two days before the day of the equinox.

It may be shown precisely in the same manner that the day in September on which the intervals of light and darkness are either exactly equal or least unequal, will be one or two days after the equinox.

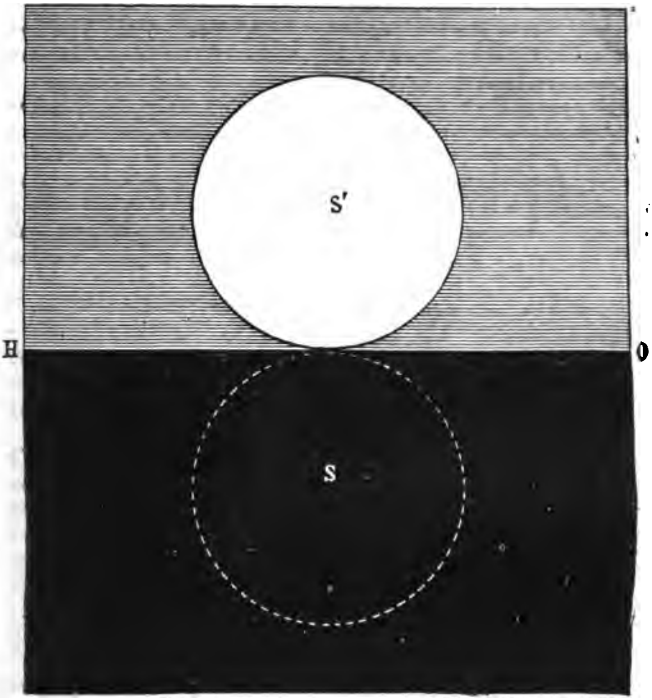
These observations may be easily verified by reference to the columns of sunrise and sunset in any almanack. Take for example that of 1854.

The March equinox took place at 20 minutes past 10 in the evening of the 20th. The day on which the intervals of light and darkness were least unequal was the 19th, upon which the sun rose at 8 minutes past 6, and set at 9 minutes past 6.

The September equinox took place at 13 minutes past 9 on the morning of the 23rd. The day and night were exactly equal on the 25th, when the sun rose at 51 minutes past 5, and set at 51 minutes past 5.

In these observations we have quoted the almanack as calculated for London, but similar consequences may be deduced from those computed for other places.

Fig. 3.



COMMON THINGS.

THE ALMANACK.

CHAPTER III.

62. Noon.—63. Clock time and sun time.—64. Declination of sun.—65. Tropics.—66. Solstices.—67. Dog days.—68. Why Midsummer is not the hottest season.—69. Unequal intervals between the equinoxes.—70. Signs of the Zodiac.—71. Their designations.—72. Tropics of Cancer and Capricorn.—73. Change of position of constellations.—74. Zodiac.—75. Ecliptic.—76. Other contents of Almanack.—77. Astronomical terms.—78. Conjunction.—79. Opposition.—80. Quadratures.—81. Morning and evening star.—82. Further illustrations.—83. Lunar changes.—84. When said to be gibbous.

62. In the daily course of the sun through the firmament, there are three important epochs, the beginning, the middle, and

the end, that is, sunrise, midday or noon, and sunset. The first and last of these having been fully explained, it remains to offer some observations on the second.

The hour of noon, or midday as commonly understood, is that at which a correctly regulated clock strikes twelve, or the moment at which the centre of the sun's disc passes the meridian, or the moment which divides the interval between sunrise and sunset into two equal parts. When these conditions come to be closely examined, however, they are found to be inconsistent one with another, the times which they severally express being in fact different.

63. It has been already explained in our Tract on "Time," that the moment at which the centre of the sun's disc passes the meridian is not that at which a correctly going clock strikes 12. The former is apparent, and the latter mean or civil noon. It is to the latter that the term noon or midday is commonly applied, and to which we shall here exclusively apply it.

Since, therefore, the moment at which the centre of the sun's disc each day passes the meridian is not the moment of noon, nor any fixed and invariable time either before or after noon, it is as necessary that the almanack should indicate from day to day what this time is, as that it should show the times of sunrise and sunset. In all good almanacks, a column is therefore appropriated to this, placed as it ought naturally to be between those which indicate sunrise and sunset. This column is variously headed, "equation of time," or "sun fast," or "sun slow," or "clock before sun," or "clock after sun," as the case may be. Whatever be the words at the head of the column, the numbers which are consigned to it are the number of minutes and seconds before or after twelve by the clock (supposed of course to be perfectly correct and to show civil or mean time *) at which the centre of the sun's disc passes the meridian.

This meridional transit of the sun's centre may vary from the hour of noon to the extent of more than sixteen minutes one way or the other.

If the almanack for 1854 be referred to, it will be seen that the meridional transit of the sun's centre took place in that year—

From 1st Jan. to 15th April .	. . in the afternoon.
,, 16th April to 14th June .	. . in the forenoon.
,, 15th June to 31st Aug.	. . in the afternoon.
,, 1st Sept. to 25th Dec. .	. . in the forenoon.
,, 25th Dec. to 31st Dec. .	. . in the afternoon.

The meridional transit of the sun's centre took place at the

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* See Tract on "Time" (36).

moment of noon on 15th April, 14th June, 31st August, and 25th December, and this takes place every year on the same days, or nearly so.

Noon does not divide the interval between sunset and sunrise into equal parts, but the moment of the meridional transit of the sun's centre does so very nearly. Now, since this may vary to the extent of 16 minutes and 18 seconds from noon, it follows that the parts into which the day is divided by noon may differ in length to the extent of 32 minutes and 36 seconds.

64. In all almanacks a column is appropriated to the sun's declination. It is therefore necessary to elucidate this technical term.

On the days of the equinoxes the sun, at the moment of its meridional transit, has a certain altitude. But for the effect of atmospheric refraction, this altitude, subtracted from ninety degrees, would leave a remainder which would be exactly equal to the latitude of the place. Since astronomers have computed and published tables which show the refraction corresponding to each altitude, the refraction can be found in these tables, and being subtracted from the observed altitude of the sun, will leave a remainder which is its true altitude.

If the altitude of the sun after the March equinox be observed daily at the moment of its meridional transit, it will be found to exceed that which it had on the day of the equinox by a constantly increasing quantity. This excess, after the effects of refraction have been allowed for in the manner just explained, is called the SUN'S DECLINATION, the sun being said to DECLINE or fall from the position it had in passing the meridian at the equinox; and since, in this case, it declines from that position towards the visible celestial pole—that is, towards the north—it is said to have NORTHERN DECLINATION.

The meridional altitude will be found to increase continually until the June solstice, when it will exceed the altitude at the equinox by 23 degrees and 28 minutes. The meridional altitude of the sun having then attained its limit, begins to decrease, and with it, of course, decreases the declination, until at length, at the time of the September equinox, it becomes nothing, the meridional altitude being again what it was at the March equinox.

Now, during all this interval, from March to September, the meridional altitude of the sun is greater than it is at the equinoxes, and the declination is consequently all the time northern.

But if the same course of observation be continued, it will be found that after the September equinox the meridional altitude will become less, and will be less and less from day to day. The sun will then *decline* more and more to the *south* of its position at the equinoxes; that is, it will have SOUTHERN DECLINATION, and its meridional altitude will continually decrease, and consequently its southern declination will continually increase until the December solstice, when it will be 23 degrees 28 minutes, just what it was at the June solstice, only that it is now that distance south of its meridional altitude at the equinoxes, whereas in June it was north of that altitude.

After the December solstice the meridional altitude will gradually increase, and consequently the southern declination will gradually decrease until the March equinox, when the declination will become nothing.

All these periodical changes in the declination may be seen by referring to the column of the almanac appropriated to it.

65. Now there are certain circumstances connected with these changes which require especial notice.

It will be observed that the northern declination of the sun continually increasing after the March equinox until the June solstice, then ceases to increase, begins to decrease, and continues to decrease until it becomes nothing at the September equinox. The sun, therefore, continually moves from its position in March, and crosses the meridian at points more and more distant from that at which it crossed it in March, until at length at the June solstice it crosses it at a distance of 23 degrees 28 minutes from the point where it crossed it in March. After that the point where it crosses the meridian begins to go back towards the point where it crossed in March, and continues to go back until it returns at the September equinox, to the point where it crossed in March.

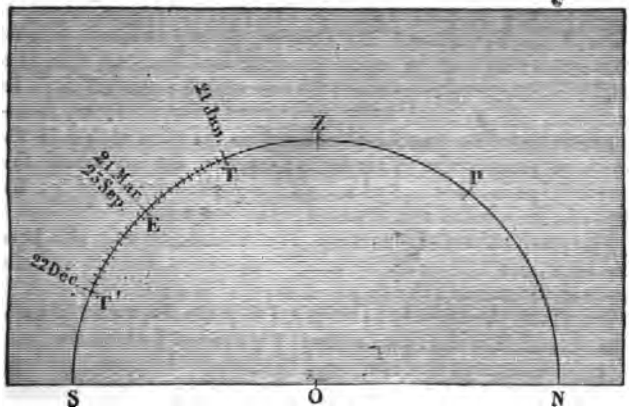
The same observations will be applicable to the points where it crosses the meridian from September to March, these points gradually receding southwards until the December solstice, and then returning back and resuming their position in March.

This will be more clearly understood by reference to fig. 4, where S N represents the horizon, S being the south, N the north, O the observer; S Z N the celestial meridian, E the point where the sun passes it at noon on the day of the equinox. Let us suppose that the equinoxes fall on the 21st March and 23rd September, and the solstices on the 21st June and 22nd December. After the 21st March the sun passes the meridian at points farther and farther above E until the 21st June, when it passes at T. After the 21st June it passes at points nearer and nearer to E until, on the 23rd September, it passes at E. After the 23rd September it passes below E lower and lower until, on the 22nd December, it passes at T′. After the 22nd December it passes at points higher and higher until the 21st March, when it passes at E.

The points T and T′ at which the sun attains its greatest distance from E, and at which, after having departed from E, it begins to return to E, are called the TROPICS from a Greek word *τροπή* (tropé), which signifies *a return.*

66. It is observed that when the sun arrives at these points T and T′, it pauses for some days without changing in any considerable degree its distance from E, and under these circumstances the hours of rising and setting continue to be sensibly the same. If, for example, the almanack be examined, it will be found that from the 10th to the 24th June the hour of sunrise does not change by more than two minutes, and that from the 13th to the 21st inclusive it does not change at all. In the same manner the hour of sunset remains the same from the 19th to the 22nd inclusive, and does not vary more than two minutes from the 17th to the 28th inclusive.

Fig. 4.



The same circumstances will be found to attend the sun when it passes the meridian at T′ in December.

Owing to this stationary position of the sun, and the consequent unchanging length of the days, these epochs are called the SOLSTICES, from a Latin word SOLSTITIUM, which denotes the *standing still of the sun.*

The June solstice is called the SUMMER SOLSTICE, and the December solstice the WINTER SOLSTICE.

They are respectively the days on which the sun attains the greatest and least meridian altitude which in the place for which the almanack is calculated it can attain, since it never can rise higher than T, or descend lower than T′ when on the meridian.

The days of the solstices are also respectively the longest and the shortest days of the year.

67. In almanacks generally the 3rd July and the 11th August are indicated as the first and last of the DOG DAYS. This comprises an interval of 40 days, which is generally the hottest part of the summer.

In the time of the ancient astronomers of Egypt and Greece, the position of the equinoctial points and the tropics which determine the limits of the seasons was different from what it is at present, and was such, that a remarkable star called Sirius, in the constellation called CANIS MAJOR or the "great dog," rose in the mornings immediately before the sun during the month of July, of which it was considered the harbinger, and whose calorific power was imagined to be increased by its influence. The idea that this star, the Dogstar as it was called, exercised such an influence, was no doubt countenanced by its extraordinary splendour, being by far the most brilliant of the stars visible in the northern hemisphere. The days, therefore, during which this star ushered in the sun, and led, as it were, his way through the heavens, were called CANICULAR DAYS or DOG DAYS.

The prevalence of canine madness at this season may also have had something to do with the name of dog days, or even with the name of the constellation to which the star in question belongs.

68. It might naturally be supposed that the days on which the sun rises highest and remains longest above the horizon ought to be the hottest, and that consequently the hottest interval of forty days should be the forty days which comprise twenty before and twenty after the summer solstice—that is, from the 2nd June to the 10th July. But this is just a month earlier than the interval which is found by observation and experience to be on an average of years the hottest part of the season. How then, it will be asked, can this be explained?

That the calorific effect of the sun is greatest on the day of the solstice is undoubtedly true; but it is easy to show that the day on which the sun imparts most heat is not the hottest day.

To explain this, so far as it depends on the position of the sun and the length of the days and nights, we are to consider the following circumstances:—

As midsummer approaches, the gradual increase of the temperature of the weather has been explained thus: The days being considerably longer than the nights, the quantity of heat imparted by the sun during the day is greater than the quantity lost during the night; and the entire result during the twenty-four hours gives an increase of heat. As this augmentation takes place after each successive day and night, the general temperature continues to increase. On the 21st of June, when the day is longest, and the night is shortest, and the sun rises highest, this augmentation reaches its maximum; but the temperature of the weather does not therefore cease to increase. After the 21st of June, there continues to be still a daily augmentation of heat, for the sun still continues to impart more heat during the day than is lost during the night. The temperature of the weather will therefore only cease to increase when, by the diminished length of the day, the increased length of the night, and the diminished meridional altitude of the sun, the heat imparted during the day is just balanced by the heat lost during the night. There will be, then, no further increase of temperature, and the heat of the weather will have attained its maximum.

But it might occur to a superficial observer, that this reasoning would lead to the conclusion that the weather would continue to increase in its temperature, until the length of the days would become equal to the length of the nights; and such would be the case, if the loss of heat per hour during the night were equal to the gain of heat per hour during the day. But such is not the case; the loss is more rapid than the gain, and the consequence is, that the hottest day usually comes within the month of July, but always long before the day of the autumnal equinox.

The same reasoning will explain why the coldest weather does not usually occur on the 21st of December, when the day is shortest and the night longest, and when the sun attains the lowest meridional altitude. The decrease of the temperature of the weather depends upon the loss of heat during the night being greater than the gain during the day; and until, by the increased length of the day and the diminished length of the night, these effects are balanced, the coldest weather will not be attained.

These observations must be understood as applying only so far as the temperature of the weather is affected by the sun, and by the length of the days and nights. There are a variety of other local and geographical causes which interfere with these effects, and vary them at different times and places.

69. Since the sun moves through one-half of the circumference of the heavens between the 20th of March and the 23rd of September, and through the other half between the 23rd of September and the 20th of March, in each half-year moving over 180° of the ecliptic (the name given to the apparent course of the sun over the firmament), it might be inferred that these two intervals must necessarily be equal. But if we take account of the days included in them respectively, we shall find that such is not the case.

The numbers of days in the two intervals in 1854, for example, were:—

20th March to 23rd Sept.	
March	11
April	30
May	31
June	30
July	31
August	31
September	23
Total	187

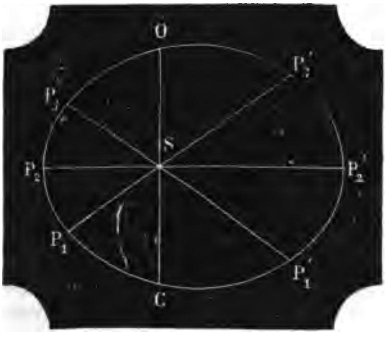
23rd Sept. to 20th March.	
September	7
October	31
November	30
December	31
January	31
February	28
March	20
Total	178

It appears, therefore, that the one exceeds the other by nine days.

Now, since in each interval the sun moves over the same space of the heavens, *i. e.* 180°, it follows, that its mean motion during the winter half-year must be faster than during the summer half-year, in the proportion of 187 to 178.

To explain this fact, it will be necessary to refer to the motion of the earth round the sun, which is the cause producing the apparent annual motion of the sun round the heavens.

Fig. 5.



The orbit or path which the earth follows in its course round the sun is not circular, but slightly oval. It may be supposed to be represented by P_2 O P'_2 C, fig. 5, S being the place of the sun nearer to one end, P_2, of the oval than to the other end, P'_2. The speed with which the earth would move if its path were a circle, with the sun in the centre, would be uniform; but in the oval, its distance from the sun varying, its speed will also vary, being greater at less, and less at greater distances. Thus, its speed at P_2, where it is nearest the sun, is greatest, and at P'_2, where it is most remote from the sun, least. The speed decreases continually while the earth moves from P_2 to P'_2, and increases continually while it moves from P'_2 to P_2. If the oval be divided into equal parts by the line P_2 S P'_2, the times of moving through each half of it will be equal; and if it had so happened that the earth should be at these two points, P_2 and P'_2, on the days of the equinoxes, then the summer and winter half-years would be exactly equal. But such is not the case. The earth, on the contrary, in

1854, was at the points C and O on the 20th of March and the 23rd of September, so that it moved from C through O to C, between the 20th of March and the 23rd of September, and from O through C to O, between the 23rd of September and the 20th of March. Now, not only is the latter segment of the oval shorter than the former, but the motion of the earth while passing over it is more rapid. On both accounts, therefore, the time of moving from O to C is less than the time of moving from C to O; and, accordingly, we find that the interval from the 20th of March to the 23rd of September is nine days longer than the interval from the 23rd of September to the 20th of March.

It may here be observed in passing as a curious fact, that the earth is nearer the sun at the winter than at the summer solstice, and it might therefore be supposed that the temperature of the seasons ought to be reversed. But the effect of this difference of distance is incomparably smaller than the effect due to the greater length of the day and the greater altitude of the sun, and these latter consequently predominate.

70. The sun moving in a year round the entire ecliptic, and therefore passing over 360°, moves over 30° per month. The ecliptic being conceived therefore to be divided into twelve equal parts of 30°, each of these parts is called a SIGN.

A certain zone of the heavens, extending to about 9° at each side of the ecliptic, is called the ZODIAC.

The zodiac, like the ecliptic, which runs along its middle, is conceived to be divided into twelve equal parts, called THE SIGNS OF THE ZODIAC.

The signs are supposed to begin at the point through which the sun passes at the March equinox, and to follow the course of the sun, so that the last in order of the signs is that through which the sun passes in the thirty days which precede the March equinox.

71. In ancient times the successive divisions of the zodiac which have been called signs, were occupied by certain conspicuous constellations or groups of stars, and each sign took its name from the constellation of which it was thus the place. It was and still is the custom to give names to constellations taken from animals, or mythological and historical personages. They have been generally called by their Latin names, which are given in the first column of the following table; the English names are given in the second, the symbol by which they are indicated in almanacks and calendars in the third. The days of the civil year upon which the sun enters the successive signs vary with the variation of the day of the equinox, the cause of which has been already explained. In the fourth column of the annexed table,

the days on which the sun enters them severally when the equinox falls on the 21st of March, are given.

Aries . .	Ram. . .	♈	21st March.
Taurus . .	Bull . .	♉	20th April.
Gemini . .	Twins . .	♊	21st May.
Cancer . .	Crab . .	♋	22nd June.
Leo . . .	Lion . . .	♌	23rd July.
Virgo . .	Virgin . .	♍	23rd August.
Libra . .	Balance . .	♎	23rd September.
Scorpio . .	Scorpion . .	♏	24th October.
Sagittarius .	Archer . .	♐	22nd November.
Capricornus .	Goat . .	♑	22nd December.
Aquarius .	Waterman .	♒	20th January.
Pisces . .	Fishes . .	♓	19th February.

72. It appears therefore that the day of the spring equinox the sun enters Aries, that of the summer solstice, Cancer, that of the autumn equinox, Libra, and that of the winter solstice, Capricorn.

The points through which the sun passes at the solstices have therefore been called the Tropic of Cancer and the Tropic of Capricorn respectively.

73. It has been shown in our Tract on "Time," that the equinoctial points, and consequently all the signs of the zodiac, have a slow backward motion on the firmament at the rate of a degree in 72 years. They would therefore move back through 30°, or an entire sign, in 2160 years. Now it is known that in the time of an illustrious astronomer, Hipparchus, who flourished in Rhodes and Alexandria about 150 years before Christ, that is above 2000 years ago, the vernal equinoctial point was in the constellation of Aries, from which the first sign of the zodiac took its name, and consequently that all the other zodiacal constellations were at the same epoch in their proper signs. But in the interval of 2000 years, the equinoctial points having, as above stated, moved backwards through about 30°, they have severally retired from their proper constellations, which are now consequently that distance before them; so that the second sign of the zodiac is occupied by the constellation Aries, which gave its name to the First sign, the third by the constellation Taurus, which gave its name to the Second sign, and so on.

Although the twelve divisions of the zodiac have thus deserted their proper constellations, they have nevertheless retained their names. It is therefore very necessary to know that there is a great difference between the SIGN ARIES and the CONSTELLATION ARIES. The former merely signifies the first 30° of the ecliptic or of the zodiac, counting from the place of the sun on the 21st of March. The other signifies a certain group of stars, through which at present the sun passes in the month of February; and a like observation will be applicable to the two senses attached to Taurus, Gemini, and the other zodiacal names.

74. The name ZODIAC is derived from the Greek word ζωδίον (*Zodion*), a little animal, the fancied figures of the constellations being generally animals.

75. The circle of the heavens called the Ecliptic, along which the sun holds its annual course, lies along the middle of the celestial zone of the zodiac, and within this zone the planets are generally confined. Most of them never depart from the path of the sun, even so far as the extreme limits of the zodiac. There are, however, a few of the smaller planets, called planetoids or asteroids, discovered by the labours of modern observers, which do depart beyond the limits of the zodiac to the extent of many degrees, and which are hence often called ultra-zodiacal planets.

The ECLIPTIC derives its name from the fact that eclipses, whether of the sun or moon, can never take place except when the moon is in or very near to the ecliptic. The moon, however, like the planets, never departs beyond the limits of the zodiac, her distance from the ecliptic never exceeding five degrees, that is about ten times her own apparent diameter.

76. The apparent daily and yearly motions of the sun on the heavens are not at all the only celestial phenomena which are foretold in the almanacks. The diurnal motions, such as the rising, southing, and setting, and the monthly changes, of the moon, to say nothing of eclipses and other phenomena, is one of the chief purposes of the almanack to describe with the most minute precision, a precision which never fails to correspond with the phenomena when they take place.

But, besides the moon, all good almanacks give the positions in which the more conspicuous of the planets are presented, so as to become objects of easy and common observation. Thus, by the aid of an almanack, any person properly informed of the import of the terms in which the appearances and motions are described, can easily identify them when they present themselves.

The better class of almanacks also indicate the position in which, at each season of the year, the more remarkable constellations are seen during the night.

77. To profit by the mass of interesting and useful information thus supplied, it is not at all necessary to be a practical astronomer, but it *is* necessary to understand the meaning of a few astronomical terms, which fortunately admit of very easy and simple explanation.

The heavens are as thickly strewed with stars by day as by night, but they are rendered invisible by the overpowering splendour of the sun. It is only in the absence of that luminary, therefore, that such objects can be seen. One of the most interesting classes of predictions given in the almanacks are those which indicate the positions of the most remarkable celestial objects relatively to that of the sun, from time to time, through the year.

78. When an object is so placed that it is on the meridian at noon, it is said to be in CONJUNCTION. It is then in the same quarter of the heavens with the sun, and rises and sets either exactly with or very little before or after the sun. Such an object, consequently, can never be visible, at least not with the naked eye, for in some cases it may be seen by the aid of a telescope.

79. When an object is so placed that it is on the meridian at midnight, it is said to be in OPPOSITION, for it is then in the quarter of the heavens directly opposed to the sun. It rises either exactly at or very little before or after sunset, and sets either exactly at or very little before or after sunrise. Such a position is therefore the most favourable one an object can have for being observed, since it is above the horizon during the night, and below it during the day.

80. When an object is separated from the sun by a quarter of the entire circuit of the heavens, it is said to be in QUADRATURE. If in that case it be to the *East* of the sun, it follows the sun, and will arrive at the meridian six hours later than the sun, that is, at 6 P.M. If it be to the *West* of the sun, it will precede the sun, and will pass the meridian six hours before the sun, that is at 6 A.M.

81. An object which is in east quadrature will therefore rise at or a little before or after noon, and will be on the meridian at or a little before or after sunset. Such an object, therefore, will be visible towards the west from sunset to midnight, at or near which it will set.

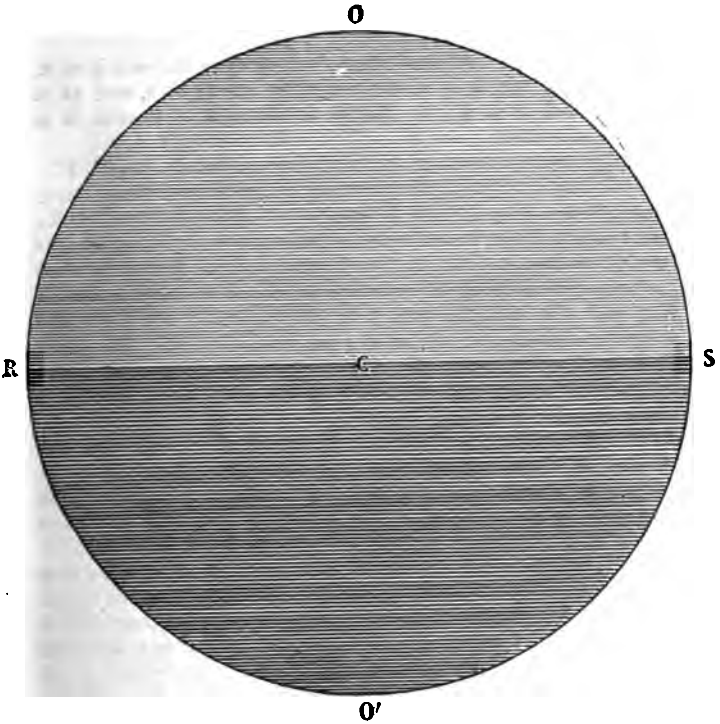
An object which is in west quadrature will, in like manner, rise at or a little before or after midnight, and will be on or near the meridian at sunrise. Such an object will therefore be seen towards the east from midnight to sunrise.

Thus, for example, when Venus, the most splendid of the planets, is removed from the sun towards the east, it is seen towards the west after sunset and continues to be visible until its own setting. It is then called the EVENING STAR. When it is removed to the west of the sun, it is seen towards the east before sunrise, and continues to be visible until it is lost in the blaze of the sun after sunrise. It is then called the MORNING STAR.

Venus as a morning star was called by the ancients LUCIFER (from the Latin words *ferre lucem*, to bring light), the Harbinger of Day. As an evening star it was called HESPERUS.

82. The preceding paragraphs will be more clearly understood by reference to fig 6. Let the observer be supposed to stand at C, with his face to the south. All objects in the heavens will then rise upon his left, R, and after ascending to the meridian, O, and descending from it, will set upon his right, S. They will pass

Fig. 6.



below the horizon, crossing the invisible half of the meridian at O′, and returning to R again to rise.

Thus, if we suppose the sun at O, which is its place at noon, an object in opposition will be at O′, and will therefore be invisible. At sunrise, the sun being at R, an object in opposition will be at or near S, and will therefore be setting; and at sunset, an object in opposition will be at or near R, and will therefore be rising. Between sunset and sunrise, the sun passing over S O′ R, an object in opposition will pass over R O S and will be at O at midnight, and will be visible in the heavens during the entire night.

An object in eastern quadrature will be at R when the sun is at O, at O when the sun is at S, at S when the sun is at O′, and at O′ when the sun is at R; so that from sunset to midnight it is visible in the west.

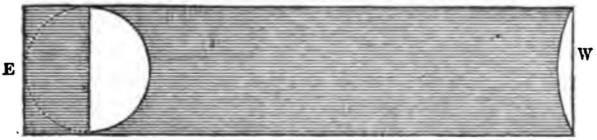
An object in western quadrature is at O when the sun is at R, at S when the sun is at O, at O′ when the sun is at S, and at R when the sun is at O′; so that from midnight to sunrise it is visible in the east.

83. It has been already shown (Museum, vol. iii. pp. 36, 37), that when the moon is in conjunction, being between the sun and the earth, and its enlightened hemisphere being presented to the sun, its dark side is turned towards the earth, so that even though it were favourably situated, it could not be seen. But from what has been just explained respecting an object in conjunction, it rises and sets with the sun, and therefore could not serve the purpose of illuminating the night even were it visible. The moon moves round the heavens from west to east at the rate of about 13° per day, while the sun moves in the same direction at the rate of about 1° per day. Therefore the moon advances eastward, departing from the sun at the rate of about 12° per day. On the 8th day, or about a week after conjunction, therefore, the moon will be 90° eastward of the sun; and, according to what was proved in vol. iii. pp. 36, 37, the moon will then be halved, the convex side of the semi-lune being presented westward towards the sun. Supposing as before, the observer to stand with his face to the south, the east will be on his left and the west on his right. In the case here supposed, therefore, the moon will appear halved as shown in fig. 7, at 90° east or to the left of the sun, and will follow the sun in its diurnal motion. The dark hemisphere of the moon indicated by the dotted semi-circle is turned eastward. The moon, therefore, in this case, moves with the straight edge of the semi-lune foremost.

This phase is called in the Almanack the FIRST QUARTER.

After conjunction, and before the moon arrives at this phase of the first quarter, it appears as a CRESCENT, the convex side of the crescent being turned westward, and towards the sun (fig. 8).

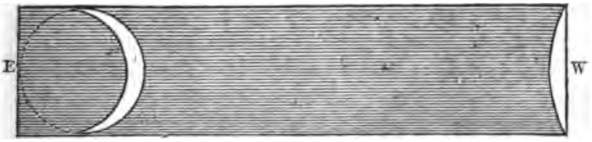
Fig. 7.



The crescent moves with its concave edge foremost. The unenlightened part of the moon is indicated by the dotted line in the figure.

In this phase the moon, not having yet arrived at the first quarter, is less than 90° east of the sun, and the less it is removed from the sun, the thinner is the crescent; and the more near it is to 90° from the sun, the more nearly does the crescent approximate to the half moon.

Fig. 8.

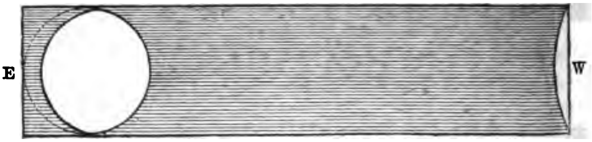


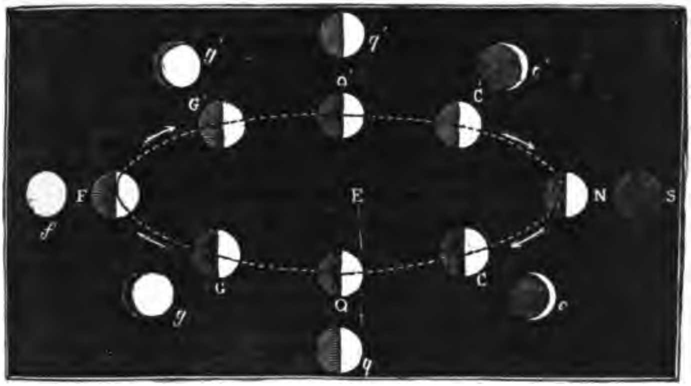
The moon being thus removed more or less to the east of the sun, or, what is the same, the sun being to the west of the moon, will set just before the moon; and the more the moon is removed from the sun, the longer will be the interval between sunset and moonset. After sunset the moon will therefore, soon after conjunction, be seen as a thin crescent in the western sky, and the farther it is removed eastward of the sun, the greater will be its altitude at sunset, the broader will be the crescent, and the larger will be the interval between sunset and moonset.

At length, when 7 days have elapsed, and the 8th day has commenced from the time of conjunction, the moon having advanced to 90° eastward of the sun, and being in quadrature, as in fig. 7, it will be on the meridian about sunset, and will not set until about midnight. Between sunset and midnight it will be seen to descend from the meridian to the western horizon.

84. Between the 8th and the 15th day from the time of conjunction, the moon, still advancing further and further eastward from the sun, will be seen eastward of the meridian at the time of sunset, and will then have the form represented in fig. 9, which is called the *gibbous* form, the edge presented westward and towards the sun being semi-circular, and that presented eastward and in the direction in which the moon is moving, being a semi-ellipse convex towards the east. This is, therefore, the form and appearance of the moon between the first quarter and the full moon, and the nearer it comes to the day of full moon—that is, to the fifteenth day from conjunction, the broader will be the gibbous disc, and the nearer will the outline approach to an exact circle.

Fig. 9.





THE LUNAR PHASES.

COMMON THINGS.

THE ALMANAC.

◆

CHAPTER IV.

85. Full moon.—86. Last quarter.—87. Moon's age.—88. Rate of motion variable.—89. Causes thereof.—90. "May moon," "March moon," &c.—91. Confusion arising from this form of expression.—92. The epochs of chronology.—93. Anno Mundi.—94. Era of Nabonassar.—95. The Hegira.

85. On the 15th day after conjunction, the moon having receded from the sun at the rate of 12° per day, will have removed to 180°, that is, to the part of the heavens directly opposite to the place of the sun, and will be full as shown in fig. 10. According to what has been explained, the full moon, being in this position, will rise about the hour of sunset, will culminate at midnight, and

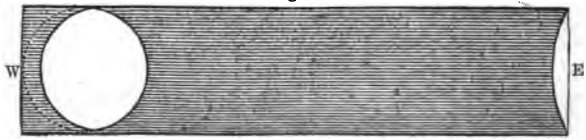
Fig. 10.

will set at sunrise. It is a remarkable character, therefore, of this arrangement that the position in which the illuminating power of the moon is greatest is precisely that in which it is present in the visible part of the firmament during the entire night.

86. After having been full, the moon still moving round the firmament in the same direction, begins to overtake the sun, and is now at less than 180° to the west of the sun; and as it advances from west to east, it approaches the sun at the rate of 12° per day; so that on the 22nd day it is only 90° west of the sun.

Between the 15th and 22nd days from conjunction, the distance of the moon west of the sun is less than 180°, but more than 90°, and according to what has been explained in vol. iii. pp. 36, 37, it is then gibbous, as shown in fig. 11, the semicircular edge being turned towards the sun, that is, towards the east, and the semi-elliptical edge towards the west. The moon now moves with the enlightened edge foremost, contrary to what took place before it was full. The unenlightened part, as before, is indicated in the figure by the dotted line.

Fig. 11.

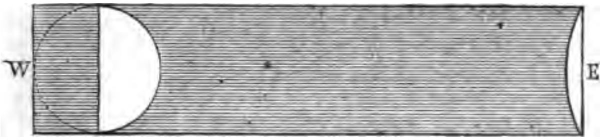


Being more than 90° to the west of the sun, the moon must now be on the west of the meridian at sunrise, and must therefore have culminated before sunrise. In this position, therefore, the moon is seen during the greater part of the night, and the early morning. It is also faintly visible in the heavens after sunrise, and until it sets, the sun's light not being sufficient to overpower it altogether.

On the 22nd day, the moon is 90° west of the sun, and is halved (fig. 2, vol. iii. pp. 36, 37). This is called in the almanack the LAST QUARTER. The moon rises at midnight and culminates about sunrise. It is therefore visible between midnight and sunrise in the eastern quarter of the heavens. After sunrise it is still faintly visible in the western quarter until it sets, which it does about the hour of noon.

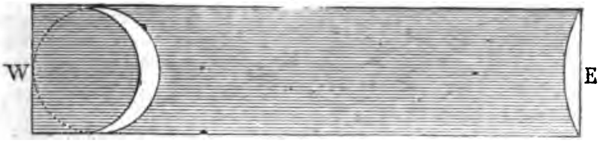
From the 22nd to the 30th day of the conjunction the moon moves constantly nearer to the sun, being now a crescent the concave side of which is turned towards the west, and the

Fig. 12.



convex side towards the sun, as shown in fig. 13, the moon still

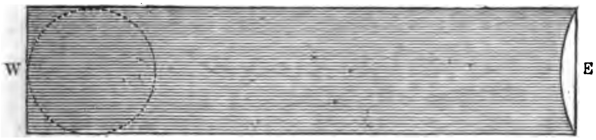
Fig. 13.



moving with the convex side of the crescent foremost. The crescent becomes thinner and thinner as the moon approaches the sun.

During this progressive change the moon being west of the sun, rises some time before it, and can be seen in the early morning, until it approaches so near the sun and until the crescent becomes so thin, that it is lost in the blaze of his splendour. The dark hemisphere is then presented to the earth, and the moon is invisible (fig. 14).

Fig. 14.



87. A column of the almanack is usually assigned to the "age of the moon." The sense in which this term is used, however, must not be confounded with that in which it is applied to the ecclesiastical moon in the rules for ascertaining the date of Easter. We are here dealing not with the fictitious but with the real moon; and the age in question is the interval which elapses between the moment of the last conjunction, and the moment at which the age professes to be assigned. This interval is usually given for the noon of each day, and is expressed in days and tenths of a day, but with still greater precision for the principal

phases, that is for conjunction, quadratures, and opposition, or as it is otherwise and more commonly expressed—for the new moon, the first quarter, the full moon, and the last quarter.

Thus, for example, when we find the moon's age on any proposed day given as 0·6, it is to be understood that at the civil or mean noon of that day, the time elapsed since the moment of conjunction was six-tenths of a day or 14 hours and 24 minutes. Again, if the age set down were 17·2, it is meant that at the noon of the day proposed an interval of 17 days and two-tenths of a day, that is 17 days 4 hours and 48 minutes, had elapsed since the moment of new moon.

88. By comparing together the dates of the successive phases of the moon as given in the almanack in each lunar month, and by comparing one with another the dates of the successive new moons, it will be found that the moon's motion during each lunar month is subject to considerable variation, and also that the length of the lunar month itself is very variable.

To render this manifest it will only be necessary to take from the almanack the dates of the phases during a lunar month, and the dates of the new moons during a year, and to compare them together.

Thus for example in the almanack for 1855 we find the following dates for the successive phases of the moon which was new on the 16th February.

		H.	M.	S.	
New Moon	February 16, at	6	47	30	p.m.
First Quarter	February 23, at	5	33	42	,,
Full Moon	March 3, at	10	8	0	,,
Last Quarter	March 11, at	1	59	18	,,
New Moon	March 18, at	4	45	12	a.m.

From which it follows that the intervals between the successive phases were—

	D.	H.	M.	S.
From New Moon to First Quarter	6	22	46	12
From First Quarter to Full Moon	8	4	34	18
From Full Moon to Last Quarter	7	15	51	18
From Last Quarter to New Moon	6	14	45	54
	29	9	57	42

Thus it appears that so far from the rate of the moon's apparent motion relatively to that of the sun being uniform through a lunar month, it is subject to so considerable a variation that while the first quarter is made in little more than 6 days 22¾ hours, the second is only completed in 8 days and 4½ hours.

If we compare the lengths of the successive lunar months we shall find a like variation. The following are the dates of twelve successive lunar months in 1855, and their lengths severally are given in the second column:—

1855.

NEW MOONS.				INTERVALS.			
	H.	M.	S.	D.	H.	M.	S.
Jan. 18	8	37	24 a.m.				
Feb. 16	6	47	30 p.m.	29	10	10	6
March 18	4	45	12 a.m.	29	9	57	42
April 16	3	4	30 p.m.	29	10	19	18
May 16	2	13	18 a.m.	29	11	8	48
June 14	2	28	54 p.m.	29	12	15	36
July 14	4	1	0 a.m.	29	13	32	6
Aug. 12	6	52	24 p.m.	29	14	51	24
Sept. 11	10	51	42 a.m.	29	15	59	18
Oct. 11	3	23	42 a.m.	29	16	32	0
Nov. 9	7	31	0 p.m.	29	16	7	18
Dec. 9	10	17	48 a.m.	29	14	46	48

Thus it appears that these eleven lunar months vary in length from $29^{d}\ 9^{h}\ 57^{m}\ 42^{s}$ to $29^{d}\ 16^{h}\ 32^{m}\ 0^{s}$, and if the comparison were carried further, a still greater variation would be found.

89. The causes of this great and apparently irregular variation in the motion of the moon are very numerous and complicated, as may be imagined when it is stated, that in order to deduce the moon's true place in the heavens at any proposed time, from its place as resulting from its mean or average motion, it is necessary to apply from thirty to forty corrections, each of which represents the effect of some disturbing force, the principal of which, however, are traceable to the varying action of the sun upon the moon.

90. It appears from the preceding table, that the day of new moon may fall indifferently upon any day of the calendar month. In common popular language, and more especially upon occasions on which certain influences are imputed (however erroneously) to the moon, that luminary is associated with the month, so that we hear of this and that effect of the "May moon," or the "March moon," and so on. Now, as neither the beginning nor the end of the age of the moon, nor even its length, has any necessary correspondence with the beginning or the end or the length of the month, it may be asked, by what condition the "May moon" is connected with May, or the "March moon" with March.

It might be imagined that the moon would take its name from the month in which it passes the greater part of its life. Such, nevertheless, is not the case. According to the most generally adopted custom, the moon takes its name from the month in which its age terminates. Thus, the May moon is that moon which ends in May, and the March moon, that which ends in March. All writers on chronology and the calendar agree in this, among whom may be cited the author of the well-known work entitled *l'Art de vérifier les Dates.*

91. Nevertheless, it must be admitted that this definition is attended with consequences which will seem rather absurd and inconsistent. Let us suppose, for example, that the moon happens to be new a little after the midnight which commences the 1st May. According to the definition, the moon which commenced its life on the 2nd April, and which finished it on the morning of the 1st May, must be called not the "April moon," but the "May moon."

But another consequence would in that case also follow, which shows in a striking manner the confusion which occasionally arises from this form of expression. In the case here supposed, the moon which was new soon after the midnight with which the 1st May commenced, would finish before the end of May, and would, therefore, according to the definition, be also called the "May moon." In fine, in such case, there would be two May moons, one whose entire age, except a few seconds, was passed in April, and the other, whose age began and ended in May.

It is easy to perceive that, the month of February in a common civil year having only 28 days, while the length of a lunar month always exceeds 29 days, it may happen that there will be no February moon. This will, in fact, occur if the moon be new on the afternoon of the 31st January.

Similar inconsistency and confusion would, however, equally ensue, if the moon took its name from the month in which it is new.

Independently of other causes of confusion arising from this custom of identifying the moon with the month in which it ends, there is the case in which the *same moon* might in one place take the name from one month, and in another place from the month preceding or following. Thus, for example, in the case of two places having a difference of longitude of 10 minutes, the hour at one place will be 10 minutes later than at the other. Now, let us suppose that the moon is new at 5 minutes before the midnight which terminates the last day of the month at one of the places. It will be new at 5 minutes after the midnight which terminates the month at the other place. Since the preceding moon ends its age in one of the places 5 minutes before the end of the month, and at the other place 5 minutes after the commencement of the next month, it will take its name at one place from the one month, and at the other from the other month. The moon which is the "May moon" of Paris may, therefore, be the "April moon" of London.

92. We shall conclude this brief exposition of the principal subjects included in the almanack, with some notice of the different epochs or eras which different nations have in different ages adopted as the zeros or starting points of their chronology.

93. It is evident that when any great event, political or religious, is adopted as the era, it would in general be necessary to count from it forwards and backwards, forwards for subsequent and backwards for preceding events. One era only would be exempt from this, and that is the era of the creation of the world, in which an event is dated Anno Mundi. Many profound researches have been accordingly made, to determine the date of this great standard of human chronology.

Unfortunately, however, the only authorities which could throw light upon the question, are involved in much obscurity, and give inconsistent results. The Hebrew, the Samaritan, and the Septuagint texts are apparently at variance on this question.

The following are the results of the researches of different chronologists as to the age of the world:—

According to Julius Africanus, the date is	5500	B.C.
According to the monk Panodorus	5493	,,
According to the Greek researches	5509	,,
Scaliger, by a comparison of different texts	3950	,,
Father Pezron	5873	,,
Jewish estimate	3761	,,
Archbishop Usher	4004	,,

The estimates of Jewish historians are, however, very various. Josephus gives it as 4163 B.C., others give it as 6524 B.C.

The estimate most commonly adopted by chronologists is that of Archbishop Usher.

The era of the Julian period has been already explained.

94. An era, called that of Nabonassar, has acquired a certain celebrity from the circumstance of its having been adopted as the point of departure in the calculations of several ancient astronomers, and more especially of Ptolemy.

The date of this era is 747 B.C.

It does not appear what circumstance determined the selection of this epoch, as there is no recorded event, social, political, or military, with which it is connected. It has been said that it is the date of the foundation of the kingdom of Babylon, out of the wreck of the Assyrian empire, after the death of Sardanapalus. It is also said that Nabonassar was the head of a new dynasty, and that he introduced the Egyptian year into Chaldea, but none of these statements have been satisfactorily proved.

95. The HEGIRA is the era of the Mohammedans. This word signifies FLIGHT, and refers to the flight of Mohammed from Mecca and his taking refuge at Medina, immediately after which his conquests commenced. The date of the Hegira is 622 A.D. But the Mohammedan year does not correspond with the Christian year, being determined by lunar months, and not by the seasons. Thus the year 1267 HEG. commenced on the 6th of November, 1850, and the year 1268 HEG. on the 26th of October, 1851, being 11 days less in length than the Christian year. The civil year of 365 days exceeds 12 mean lunar months of 29½ days by 11 days.

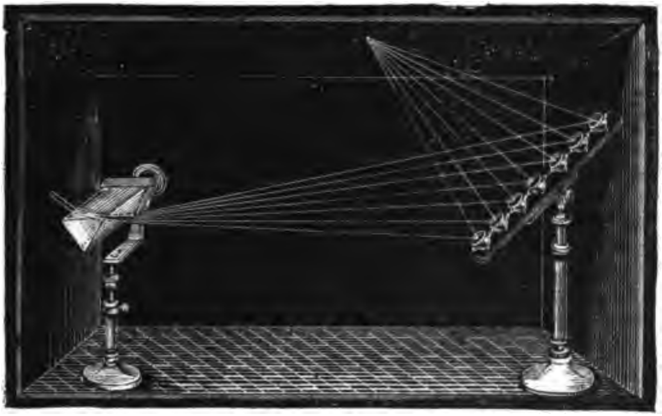


Fig. 10.—NEWTON'S EXPERIMENT SHOWING THE RECOMPOSITION OF LIGHT.

COMMON THINGS.

COLOUR.

CHAPTER I.

1. Colours depend upon reflected lights.—2. Bodies luminous and non-luminous.—3. Luminaries.—4. Non-luminous bodies.—5. Transparency and opacity.—6. Transparency never perfect.—7. Opacity never perfect.—8. Bodies rendered visible by reflected light.—9. Irregular reflection.—10. Reflecting powers vary.—11. The blackest body reflects some light—12. Irregular reflection necessary to vision.—13. Use of the atmosphere in diffusing light.

1. THE colours of objects, natural and artificial, depend on the light which they have the peculiar property of reflecting. A red object is one which is capable of reflecting red light exclusively, or at least in a much larger proportion than the lights of other colours. A green object is one which has the property of reflecting a predominance of green light, and so on.

These effects, familiar as they are to every one from the moment the senses are excited by external objects, are, nevertheless, very imperfectly understood, and often altogether misunderstood. Indeed, it was not until the time of Newton that the true physical cause of the colours of visible objects was fully explained.

The phenomena depend on certain properties of light, which must be understood before it is possible that the causes of colour can be rightly comprehended.

2. In relation to the production of light, bodies are considered as luminous and non-luminous.

3. Luminous bodies, or luminaries, are those which are original sources of light, such, for example, as the sun, the flame of a lamp or candle, metal rendered red-hot, the electric spark, lightning, and so forth.

Luminaries are necessarily always visible when present, provided the light they emit be strong enough to excite the eye.

4. Non-luminous bodies are those which themselves produce no light, but which may be rendered temporarily luminous when placed in the presence of luminous bodies. These cease, however, to be luminous, and therefore visible, the moment the luminary from which they borrow their light is removed. Thus the sun, placed in the midst of the planets, satellites, and comets, renders these bodies luminous and visible; but when any of them is removed from the solar influence by the interposition of any object not pervious by light, they cease to be visible, as is manifest in the case of lunar eclipses, when the globe of the earth is interposed between the sun and moon, and the latter object is therefore deprived of light. A candle or lamp placed in the room renders the walls, furniture, and surrounding objects temporarily luminous, and therefore visible; but if the candle be screened by any object not pervious to light, those parts of the room from which light is intercepted would become invisible, did they not receive some light from the other parts of the room still illuminated. If, however, the candle or lamp be completely covered, all the objects in the room become invisible.

5. In relation to the propagation of light, bodies are considered as transparent and opaque. Bodies through which light passes freely are called transparent, because the eye placed behind them will see such light through them. Bodies, on the contrary, which do not admit light to pass through them, are called opaque; and such bodies consequently render a luminary invisible if interposed between it and the eye.

Transparency and opacity exist in various bodies in different degrees. Glass, air, and water are examples of very transparent bodies. The metals, stone, earth, wood, &c. are examples of opaque bodies.

Correctly speaking, no body is perfectly transparent or perfectly opaque.

6. There is no substance, however transparent, which does not intercept some portion of light, however small. The light is thus intercepted in two ways; first, when the light falls upon the

surface of any body or medium, a portion of it is arrested, and either absorbed upon the surface, or reflected back from it; the remainder passes through the body or medium, but in so passing more or less of it is absorbed, and this increases according to the extent of the medium through which the light passes. Analogy, therefore, justifies the conclusion that there is no transparent medium which, if sufficiently extensive, would not absorb all the light which passes into it.

A very thin plate of glass is almost perfectly transparent, a thicker is less so, and according as the thickness is increased the transparency will be diminished. The distinctness with which objects are seen through the air diminishes as their distance increases, because more or less of the light transmitted from them is absorbed in its progress through the atmosphere. This is the case with the sun, moon, and other celestial objects, which when seen near the horizon are more dim, however clear the atmosphere may be, than when seen in the zenith. In the former case, the light transmitted from them passes through a greater mass of atmosphere, and more of it is absorbed. According to Bouguer, sea-water at about the depth of 700 feet would lose all its transparency, and the atmosphere would be impervious to the sun's light if it had a depth of 700 miles.

The transparency of the same substance varies according to the density of its structure, the transparency generally increasing with the density. Thus, charcoal is opaque, but if the same charcoal be converted into a diamond, which it may be, without any change of the matter of which it is composed, it will become transparent.

Bodies are said to be imperfectly transparent, or semi-transparent, when light passes through them so imperfectly, that the forms and colours of the objects behind them cannot be distinguished. Ground glass, paper, and thin tissues in general, foggy air, the clouds, horn, and various species of shell, such as tortoise-shell, are examples of this.

The degrees of this imperfect transparency are infinitely various, some substances, such as horn, being so nearly transparent as to render the form of a luminous object behind it indistinctly visible. Porous bodies, which are imperfectly transparent, usually have their transparency increased by filling their pores with some transparent liquid. Thus paper, which is imperfectly transparent, is rendered much more transparent by saturating it with oil, or by wetting it with any liquid. The variety of opal called hydrophane is white and opaque when dry, but when saturated with water it becomes transparent. Ground glass is rendered more transparent by pouring oil upon it. Two plates of ground glass placed one upon the other are very imperfectly transparent; but if the space between them be filled with oil, and their external surfaces be rubbed with the same liquid, they will be rendered nearly transparent.

7. Bodies, however opaque, lose their perfect opacity when reduced to the form of extremely attenuated laminæ. Gold, one of the most dense of metals, is, in a state of ordinary thickness, perfectly opaque; but if it be reduced to the form of leaf-gold by the process of the gold-beater, and attached to a plate of glass, light will pass partially through it, and to an eye placed behind it, it will appear of a greenish colour. Other metals, when equally attenuated, show the same imperfect opacity.

8. When rays of light encounter the surface of an opaque body, they are arrested in their progress, such surfaces not being penetrable by them. A certain part of them, more or less according to the quality of the surface and the nature of the body, is absorbed, and the remaining part is driven back into the medium from which the rays proceed. This recoil of the rays from the surface on which they strike is called *reflection*, and the light thus returning into the same medium from which it had arrived, is said to be *reflected.*

The manner in which the light is reflected from such a surface varies according as the surface is polished or unpolished, and according to the degree to which it is polished.

If light fall upon a uniformly rough surface of an opaque body, each point of such surface becomes the focus of a pencil of reflected light, the rays of such pencil diverging equally in all directions from such focus.

The pencils which thus radiate from the various points are those which render the surface visible. If the light were not thus reflected indifferently in all directions from each point of the surface, the surface would not be visible, as it is from whatever point it may be viewed.

The light which is thus reflected from the various points upon the surface of any opaque body, has the colour which is commonly imputed to the body. The conditions, however, which determine the colour of bodies will be fully explained hereafter. For the present, it will be sufficient to establish the fact, that each point of the surface of an opaque body which is illuminated is an independent focus from which light radiates, having the colour proper to such point, by which light each such point is rendered visible.

9. This mode of reflection, by which the forms and qualities of all external objects are rendered manifest to sight, has been generally denominated, though not as it should seem with strict propriety, the irregular reflection of light.

There is, nevertheless, nothing irregular in the character of the phenomena. The direction of the reflected rays is independent of each of the incident rays; but, nevertheless, such direction obeys the common law of radiation.

The existence of these radiant pencils proceeding from the surface of any illuminated object, and their independent propagation through the surrounding space, may be rendered still more manifest by the following experiment.

Let A B, fig. 1, be an illuminated object, placed before the window-shutter of a darkened room. Let *c* be a small hole made in the window-shutter, opposite the centre of the object. If a screen be held parallel to the window-shutter, and the object at some distance from the hole, an inverted picture of the object will be seen upon it, in which the form and colour of the object will be preserved; the magnitude, however, of such picture will vary according to the distance of the screen from the aperture. The less such distance, the less will be the magnitude of the picture.

Fig. 1.

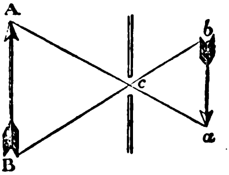


Fig. 2.

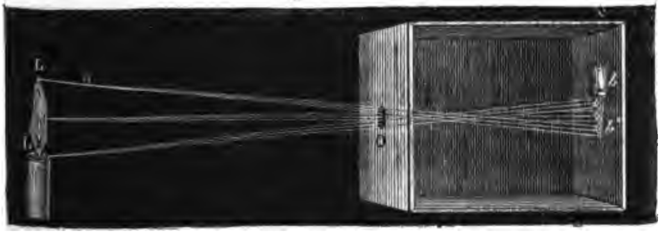
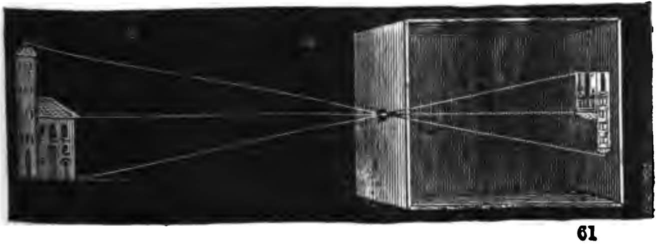


Fig. 3.



Whether the object is luminous, as in fig. 2, or one which receives light from a luminary, as in fig. 3, the image will be equally produced and inverted, only it will be less brilliant in the case of an object illuminated by another, as in fig. 3, than in that of a luminary, as in fig. 2.

This effect is easily explained. According to what has been already stated, each point of the surface of the illuminated object A B is a focus of a pencil of rays of light having the colour peculiar to such point. Thus, each portion of the pencil of rays which radiates from the point B, and has for its base the area of the aperture *c*, will pass through the aperture, and will continue its rectilinear course until it arrives at the point *b* upon the screen, where it will produce an illuminated point corresponding in colour to the point B.

In the same manner, the pencil diverging from A, and passing through the aperture *c*, will produce an illuminated point on the screen at *a*, corresponding in colour to the point A.

Each intermediate point of the object will produce a corresponding illuminated point on the screen. It is evident, therefore, that a series of illuminated points corresponding in arrangement and colour to those of the object will be formed upon the screen between *a* and *b*, their position, however, being inverted, the points which are highest in the object will be lowest in the picture.

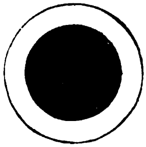
These effects may be witnessed in an interesting manner in any room which is exposed to a public thoroughfare frequented by moving objects. Let the window-shutters be closed and the interstices stopped so as to exclude all light except that which enters through any small hole in them, and if no hole be found in the shutters sufficiently small, a piece of paper or card may be pasted over any convenient aperture, and a hole of the required magnitude pierced in it. Coloured inverted images of all the objects passing before the window will thus be depicted on a screen conveniently placed. They will be exhibited on the opposite wall of the room; but unless the wall be white, the colours will not be distinctly perceptible. The smaller the hole admitting the light is, the more distinct but the less bright the pictures will be. As the hole is enlarged the brightness increases, but the distinctness diminishes. The want of distinctness arises from the spots of light on the screen, produced by each point of the object overlaying each other, so as to produce a confused effect.

10. Surfaces differ from each other in the proportion of light which they reflect and absorb. In general, the lighter the colour, other things being the same, the more light will be reflected and the less absorbed, and the darker the colour the less will be reflected and the more absorbed; but even the most intense black reflects some light. A surface of black velvet, or one blackened with lamp-black, are among the darkest known, yet each of these

reflects a certain quantity of rays. That they do so we perceive by the fact that they are visible. The eye recognises such surfaces as differing from a dark aperture not occupied by any material surface, and it can only thus recognise the appearance of the material surface by the light which it reflects. The following experiment, however, will render this more evident.

11. Blacken the inside of a tube, and fasten upon the extremity remote from the eye a plate of glass. To the centre of this plate of glass attach a circular opaque disk, somewhat less in diameter than the tube, so that in looking through the tube a transparent ring will be visible, as represented in fig. 4. In the centre of this transparent ring will appear an intensely dark circular space, being that occupied by the disk attached to the glass.

Fig. 4.



Now, let a piece of black velvet be held opposite the end of the tube, so as to be visible through the transparent ring. If the velvet reflected no light, then the transparent ring would become as dark as the disk in the centre; but that will not be the case. The velvet will appear by contrast with the disk, not black, but of a greyish colour, proving that a certain portion of light is reflected, which in this case is rendered perceptible by the removal of the brighter objects from the eye.

12. Irregular reflection, as it has been so improperly called, is one of the properties of light which is most essential to the efficiency of vision.

Without irregular reflection, light must be either absorbed by the surfaces on which it falls, or it must be regularly reflected. If the light which proceeds from luminous objects, natural or artificial, were absorbed by the surface of objects not luminous, then the only visible objects in the universe would be the sun, the stars, and artificial lights, such as flames,

These luminaries would, however, render nothing visible but themselves.

If the light radiating from luminous objects were only reflected regularly from the surface of non-luminous objects, these latter would still be invisible. They would have the effect of so many mirrors, in which the images of the luminous objects only could be seen. Thus, in the day-time, the image of the sun would be reflected from the surface of all objects around us, as if they were composed of looking-glass, but the objects themselves would be invisible. The moon would be as though it were a spherical mirror, in which the image of the sun only would be seen. A room in which artificial lights were placed would reflect these lights from the walls and other objects around as if they were specula, and all that would be visible would be the multiplied reflections of the artificial lights.

Irregular reflection, then, alone renders the forms and qualities of objects visible. It is not, however, merely by the first irregular reflection of light proceeding from luminaries by which this is effected. Objects illuminated and reflecting irregularly the light from their surfaces, become themselves, so to speak, secondary luminaries, by which other objects not within the direct influence of any luminary, are enlightened, and these in their turn reflecting light irregularly from their surfaces, illuminate others, which again perform the same part to another series of objects. Thus light is reverberated from object to object through an infinite series of reflections, so as to render innumerable objects visible which are altogether removed from the direct influence of any natural or artificial source of light.

13. The globe of the earth is surrounded with a mass of atmosphere extending forty or fifty miles above the surface.

The mass of air which thus envelopes the hemisphere of the earth presented towards the sun, is strongly illuminated by the solar light, and, like all other bodies, reflects irregularly this light. Each particle of air thus becomes a luminous centre, from which light radiates in every direction. In this manner, the atmosphere diffuses in all directions the light of the sun by irregular reflection. Were it not for this, the sun's light could only penetrate those spaces which are directly accessible to his rays. Thus, the sun shining upon the window of an apartment would illuminate just so much of that apartment as would be exposed to his direct rays, the rest remaining in darkness. But we find, on the contrary, that although that part of the room upon which the sun directly shines is more brilliantly illuminated than the surrounding parts, these latter are nevertheless strongly illuminated. All this light proceeds from the irregular reflection of the mass of atmosphere just mentioned.

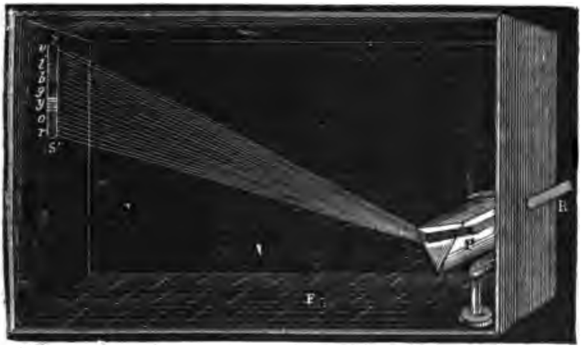


Fig. 7.—NEWTON'S CELEBRATED EXPERIMENT SHOWING THE DECOMPOSITION OF LIGHT.

COMMON THINGS.

COLOUR.

CHAPTER II.

14. Diffusion of light by all visible objects.—15. Decomposition of light by visible objects.—16. Experimental proof of the composition of light.—17. The prismatic spectrum.—18. The composition of solar light—19. The recomposition of light by prism and concave reflector.—20. The same by prism and lens.—21. The same with artificial colours.—22. Light of the same colour may have different refrangibilities.—23. Colours produced by combining different rays of the spectrum.—24. Complementary colours.—25. Colours of natural bodies generally compound.—26. Method of observing the spectrum by direct vision.—27. Why objects seen through prism are fringed with colours.—28. The prismatic colours, not all simple.—29. Sir D. Brewster's analysis of the spectrum.

14. But the solar light is further diffused by being again irregularly reflected from the surface of all the natural objects upon which it falls. The light thus irregularly reflected from the air falling upon all natural objects, is again reciprocally reflected from one to another of these through an indefinite series of multiplied reflections, so as to produce that diffused and general illumination which is necessary for the purposes of vision.

Light and shade are relative terms, signifying only different degrees of illumination. There is no shade so dark into which some light does not penetrate.

It is the same with artificial lights. A lamp placed in a room illuminates directly all those objects accessible to its rays. These objects reflect irregularly the light incident upon them, and illuminate thus more faintly others which are removed from the direct influence of the lamp, and thus, these again reflecting the light, illuminate a third series still more faintly; and so on. When it is desired to diffuse uniformly by reflection the light which radiates from a luminary, the object is often more effectually attained by means of an unpolished opaque reflector than by a polished one. White paper or card answers this purpose very effectually. Shades formed into conical surfaces placed over lamps are thus found to diffuse by reflection the light in particular directions, as in the case of billiard-tables or dinner-tables, where a uniformly diffused light is required. A polished reflector, in a like case, is found to diffuse light much more unequally.

In case of white paper or card, each point becomes a centre of radiation, and a general and uniform illumination is the consequence. The light obtained by reflection in such cases is always augmented by rendering the reflector perfectly opaque; for if it be in any degree transparent, as is sometimes the case with paper shades put over lamps, the light which passes through them is necessarily subtracted from that which is reflected.

15. We have stated that the colour of objects is that of the light which they reflect. It may then be asked how it happens that objects illuminated by the white light of the sun are not all white instead of having the infinitely various tints of colour by which they are characterised. The answer is, that the white light of the sun itself is a composition of all these various hues; that some objects reflect only the component lights of particular tints, and others those of other tints; that, in fact, the solar light falling on an object is generally decomposed, a part of it being absorbed by, or transmitted through, the object, and a part only reflected, and the object appears to have the colour peculiar to this latter part.

16. That solar light is actually a compound of lights of various tints was established by Newton by means of a memorable and beautiful experiment.

Let a ray of solar light be admitted through a small hole, P (fig. 5.) in a screen or partition S T, all other light being excluded from the space into which the pencil enters. If a white screen X Z be placed parallel to S T, and at a distance from it of about 12 feet, a circular spot of light nearly equal in diameter to the hole will appear upon it at P′, the point where the direction of the pencil meets the screen. Now let a glass prism, such as is shown in fig. 6, be placed at A B C, with the edge of its refracting angle B in a horizontal direction, and presented downwards so as to receive the pencil upon its side A B at Q. According to a well known principle in optics, the pencil would be refracted, in passing through the surface A B, in the direction Q L towards the perpendicular; and it would be again refracted, in emerging from the surface C B, from the perpendicular in the direction L K. It might therefore be expected that the effect of the prism would be merely to move the spot of light from P′ to some point, such as K, more elevated upon the screen. The phenomenon, however, will be very different. Instead of a spot of light, the screen will present an oblong coloured space, the outline of which is represented at M N as it would appear when viewed in front of the screen. A perspective view of the arrangement for making this celebrated experiment is given in fig. 7, p. 65.

Fig. 5.

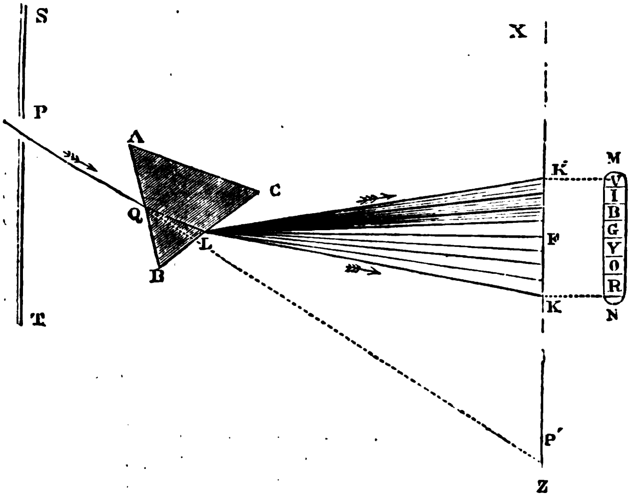
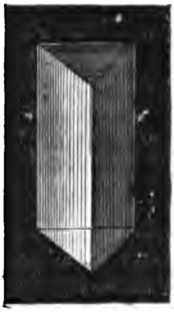


Fig. 6.



17. The sides of this oblong figure are parallel, straight, and vertical. Its ends are semi-circular, and its length consists of

a series of seven spaces, vividly coloured, the lowest space being red, R; the next in ascending, orange, O; and the succeeding spaces, yellow, Y; green, G; light blue, B; dark blue or indigo, I; and, in fine, violet, V.

These several coloured spaces are neither equal in magnitude nor uniform in colour. The red space R, commencing at the lowest point with a faint red, increases in brilliancy and intensity upwards. The red, losing its intensity, gradually melts into the orange, so that there is no definite line indicating where the red ends and the orange begins. In the same manner, the orange, attaining its greatest intensity near the middle of the space, gradually melts into the yellow; and in the same manner, each of the succeeding colours, having their greatest intensities near the middle of the spaces, melts towards its extremities into the adjacent colours.

The proportion of the whole length occupied by each space will depend upon the sort of glass of which the prism is composed. If it be flint-glass, and the entire length M N be supposed to consist of 360 equal parts, the following will be the length of each succeeding colour, commencing from the red upwards.

Red	56
Orange	27
Yellow	27
Green	46
Blue	48
Indigo	47
Violet	109
	360

It appears, therefore, that the ray of light P Q, after passing through the prism, is not only deflected from its original course P Q P′, but it is resolved into an infinite number of separate rays of light which diverge in a fan-like form, the extreme rays being L K and L K′, the former being directed to the lowest point of the coloured space upon the screen, and the latter to the highest point. The coloured space thus formed upon the screen is called the *prismatic spectrum.*

18. From this experiment the following consequences are inferred:—

1°. Solar light is a compound principle, composed of several parts differing from each other in their properties.

2°. The several parts composing solar light differ from each other in refrangibility, those rays which are directed to the lowest part of the spectrum being the least refrangible, and those directed to the highest part being the most refrangible; the rays directed to the intermediate parts having intermediate degrees of refrangibility.

3°. Rays which are differently refrangible are also differently coloured.

4°. The least refrangible rays composing solar light are the red rays, which compose the lowest division R of the spectrum. But these red rays are not all equally refrangible, nor are they precisely of the same colour. The most refrangible red rays are those which are deflected to the lowest point of the red space R, and the least refrangible are those which are directed to the point where the red melts into the orange. Between these there are an infinite number of red rays having intermediate degrees of refrangibility. The colour of the red rays varies with their refrangibility, the most intense red being that of rays whose refrangibility is intermediate between those of the extreme rays of the red space.

The same observations will be applicable to rays of all the other colours.

5°. Each of these components of solar light having a different refrangibility will have for each transparent substance a different index of refraction. Thus the index of refraction of the red rays will be less than the index of refraction of the orange rays, and that of these latter will be less than the index of refraction of the yellow rays, and so on; the index of refraction of violet rays being greater than for any other colour.

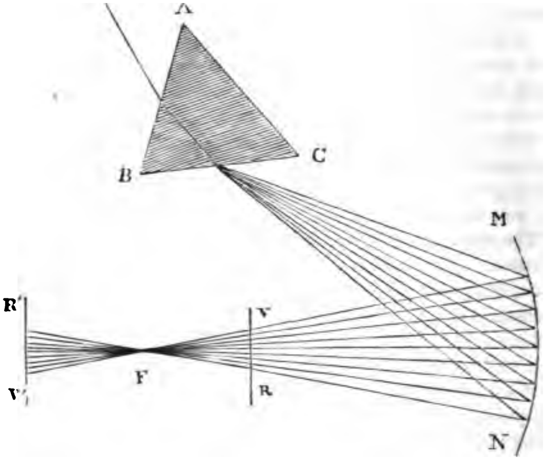
But the rays of each colour being themselves differently refrangible, according as they fall on different parts of the coloured space, they will, strictly speaking, have different indices of refraction. The index of refraction, therefore, of any particular colour must be understood as expressing the index of refraction of the middle or mean ray of that particular colour. Thus, the index of refraction of the red rays will be the index of refraction of the middle ray of the red space; the index of refraction of the orange rays will be the index of refraction of the middle ray of the orange space; and so on.

It must not, however, be supposed that a pencil of solar light consists of separate and distinct rays of different colours which form the spectrum, so that it might be possible by any mechanical division of such a pencil to resolve it into such rays. Each individual ray of such a pencil is composed of all the rays of the spectrum, just as the gases oxygen and hydrogen, which are the chemical constituents of water, enter into the composition of each particle of that liquid, no matter how minute it be.

19. As the solar light is resolved by the prism into the various

coloured lights exhibited in the spectrum, it might be expected that, these coloured lights being mixed together in the proportion in which they are found in the spectrum, white light would be reproduced. This is accordingly found to be the case. If the spectrum formed by the prism A B C (fig. 8.) instead of being thrown upon a screen, be received upon a concave reflector M N, the rays which diverged from the prism and formed the spectrum will be reflected converging to the focus F; and after intersecting each other at that point, they will again diverge, the ray R F passing in the direction F R′, and V F in the direction F V′.

Fig. 8.



Now, if a screen be held between F and the reflector, the spectrum will be seen upon the screen. If the screen be then moved from the reflector towards the focus F, the spectrum upon the screen will gradually diminish in length, the extreme colours R and V approaching each other. When it comes so near to F that the extreme limits of the red and violet touch each other, the central point of the spectrum will become white; and when the screen arrives at the point F, the coloured rays being all mingled together, the spectrum will be reduced to a white colourless spot.

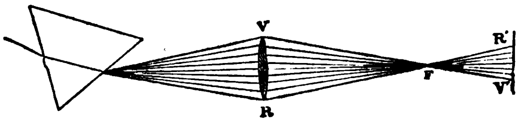
Just before the screen arrives at F, it will present the appearance of a white spot, fringed at the top with the colours forming the upper end of the spectrum, violet, blue, and green, and at the bottom with those forming the lower end of the spectrum, red, orange, and yellow. This effect is explained by the fact, that until the screen is brought to the focus F, the extreme rays at the other end of the spectrum are not combined with the other colours.

If the screen be removed beyond F, the same succession of appearances will be produced upon it as were exhibited in its approach to F, but the colours will be shown in a reversed position.

As the screen leaves F, the white spot upon it is fringed as before, but the upper fringe is composed of red, orange, and yellow, while the lower is composed of violet, blue, and green; and when the screen is removed so far from the focus F as to prevent the superposition of the colours, the spectrum will be produced upon it, with the red at the top, and the violet at the bottom, the position being inverted with respect to that which the screen exhibited at the other side of the focus. These circumstances are all explained by the fact that the rays converging to F intersect each other there.

20. Similar effects may be produced by receiving the spectrum upon a double convex lens, as represented in fig. 9. The rays are made as before to converge to a focus F, where a white spot would be produced upon the screen. Before the screen arrives at F, and after it passes it, the same effects will be produced as with the concave reflector.

Fig. 9.

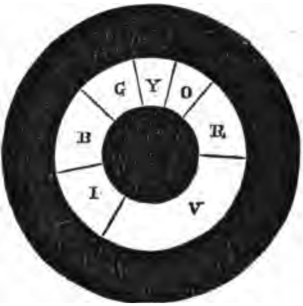


21. The proposition, that the combination of colours exhibited in the prismatic spectrum produces whiteness, may be further verified by the following experiment:—

Let a circular card be framed with a blackened circle, and its centre surrounded by a white circular band, and a black external border, as represented in fig. 11.

Let the white circular band be divided into seven spaces proportional in magnitude to the spaces occupied by the seven colours in the prismatic spectrum, these spaces being R, O, Y, G, B, I, and V. Let these spaces be respectively coloured with artificial colours resembling as near as practicable in their tints the colours of the spectrum. If the centre of this card be placed upon a spindle, and a very rapid motion of rotation be imparted to it, the ring on

Fig. 11.



which the seven colours are painted will present the appearance of a greyish white. In this case, if all the colours except one were covered with black, the revolving card would present the appearance of a continuous ring of that colour; and, consequently, if all the coloured spaces be uncovered, seven continuous rings of the several colours would be produced; but these rings being superposed and mingled together will produce the same effect on the sight as if all the seven colours were mixed together in the proportion which they occupy on the card. If the colours were as intense and as pure as they are in the spectrum, the revolving card would exhibit a perfectly white ring; but as the colours of natural bodies are never perfectly pure, the colour produced in this case is greyish.

This experiment may be further varied by leaving uncovered any two, three, or more combinations of the colours depicted on the card. In such case the rotation of the card produces the appearance of a ring of that colour which would result from the mixture of the colours left uncovered; thus, if the red and yellow spaces remain uncovered, the card will produce the appearance of an orange ring; if the yellow and blue remain uncovered, it will produce the appearance of a green ring; and so on.

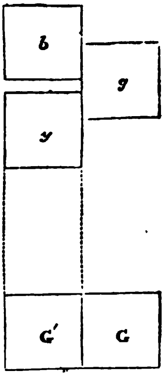
The following pretty experiment, illustrating the recomposition of light, was suggested by Newton.

The spectrum is received upon seven plane reflectors, as shown in fig. 10, p. 57, which are so suspended as to be capable of shifting their planes at pleasure. They are so adjusted as to receive the light proceeding from the prism, which correspond to the seven different colours, and to reflect it to the same point upon a screen conveniently placed, or upon the ceiling of the room. The spot of light thus produced will be white.

22. Although the phenomena attending the prismatic spectrum prove that rays of light which differ in refrangibility also differ in colour, the converse of this proposition must not be inferred; for it is easy to show that two lights which are of precisely the same colour, may suffer very different effects when transmitted through a prism.

Let us suppose two holes made in the screen on which the spectrum is thrown in the middle of the space occupied by the blue and yellow colours, so that rays of these colours may be transmitted through the holes. Let these rays be received upon a double convex lens, and brought to a focus at G′, (fig. 12) upon a sheet of white paper, so as to illuminate the spot G′. The colour that it produces then will be a green. Let another spectrum be now thrown by a prism upon the screen, and let a hole be made in the screen at that part of the green space where the tint is precisely similar to the colour produced at G′ on the white paper, and let the light which passes through this hole fall upon the spot G beyond G′.

Fig. 12.



The spaces G and G′ will then be illuminated by lights of precisely the same colour; but it will be easy to show that these lights are not similarly refrangible.

Let them be viewed through a prism having its refracting angle presented upwards. The image of the illuminated space G will be seen in a more elevated position at *g*; but two images will be produced of the space G′, one yellow and the other blue at *y* and *b*, the yellow image *y* being a little below *g*, and the blue image *b* a little above it. Thus it is evident that the green light on the space G′ is a compound of yellow and blue, and is separable into its constituents by refraction, while the similar green light on the space G is incapable of decomposition by refraction.

23. An endless variety of tints may be produced by combining in various ways the colours composing the prismatic spectrum; indeed, there is no colour whatever which may not be produced by some combination of these tints. Thus, all the shades of red may be produced by combining some proportion of the yellow and orange with the prismatic red; all the shades of orange may be produced by combining more or less of the red and yellow with each other and with the orange; all the shades of yellow may

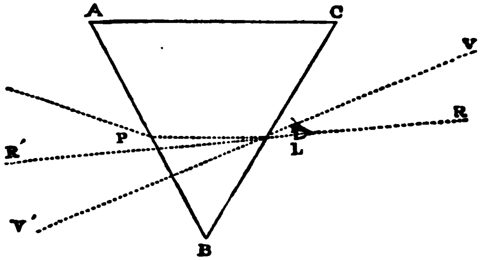
be produced by varying the proportion of green, yellow, and orange; and so on.

24. If two tints T and T′ be produced, the former T by combining a certain number of prismatic colours, and the latter T′ by combining the remainder together, these two tints T and T′ are called *complementary*, because each of these contains just those colours which the other wants to produce complete whiteness; and, consequently, if the two be mixed together, whiteness will be the result. Thus, a colour produced by the combination of the red, orange, yellow, and green of the spectrum in their just proportions, will be complementary to another colour produced by the blue, indigo, and violet in their just proportions, and these two colours, if mixed together, would produce whiteness.

25. Almost all colours, natural or artificial, except those of the prismatic spectrum itself, are more or less compounded, and their combined character belongs to them equally when they have tints identical with the coloured spaces of the spectrum. Thus, a natural object whose colour is indistinguishable from the yellow space of the spectrum, will be found, when subjected to the action of the prism, to refract light in which there is more or less of green or orange; and an object which appears blue will be found to have in its colour more or less of green and violet.

26. Instead of receiving the spectrum on a screen, it may be viewed directly by placing the eye behind the prism A B C, fig. 13 at L, so as to receive the light as it emerges. This mode of observing the prismatic effects is in many cases more convenient than by means of the screen, colours being thus rendered observable which would be too feeble to be visible after reflection from the surface of the screen. It is necessary, however, to consider that in this manner of viewing the prismatic phenomena, the colours will be seen in an order the reverse of that which they would hold on the screen; for if the eye be placed at L, it will

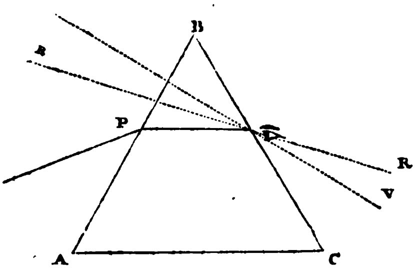
Fig. 13.



receive the violet ray which enters in the direction L V as if such ray had proceeded from V′, and it will receive the red ray which enters it in the direction R as if it had proceeded from R′; the red will therefore appear at the top, and the violet at the bottom of the spectrum, when the refracting angle B of the prism is turned downwards.

But if the refracting angle B be turned upwards, as represented in fig. 14, then the red will appear at the bottom, and the violet at the top of the spectrum, as will be perceived from the figure.

Fig. 14.



27. In general, when objects are viewed through a prism they appear with their proper colours, except at their boundaries, where they are fringed with the prismatic tints in directions parallel to the edge of the refracting angle of the prism.

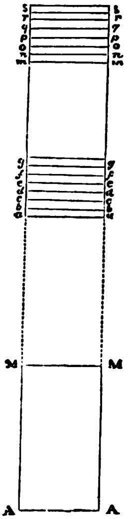
Let A A M M, (fig. 15,) be a small rectangular object seen upon a black ground, the sides A M being vertical, and A A and M M horizontal. Let us first suppose that this object has the colour of a pure homogeneous red. If this object be viewed through a prism whose refracting angle is directed upwards with its edge horizontal, it will be seen in a more elevated position, such as *a a m m*, as already explained.

Let us next suppose that the object A A M M has the colour of a pure homogeneous orange. When viewed through the prism it will, as already explained, appear in a position *b b n n*, a little above *a a m m*.

If we next suppose the object A A M M to be coloured with homogeneous yellow, it will be raised by the prism to *c c o o*, a little above the orange image.

If it be next supposed to have the colour of a prismatic green, it will be seen at *d d p p*, a little above the yellow image; and if it be coloured light blue, its image will be seen at *e e q q*, above the green image; if it be dark blue or indigo, its image will be in the position *f f r r;* if it be violet, its image will be in the position *g g s s.*

Fig. 15.



Now, if we suppose the object A A M M to be white, that is to say, to have a colour which combines all the prismatic colours together, then all these several images will be seen at once through the prism in the respective positions already described. They will therefore be more or less superposed one upon the other, and the image will exhibit in its different parts those tints which correspond to the mixture of the colours thus superposed.

Hence it appears that the space between *a a* and *b b* from which all colour except the red is excluded, will appear red; in the space between *b b* and *c c*, in which the orange image is superposed upon the red image, a colour will be exhibited corresponding to the mixture of these two colours; in the space between *c c* and *d d*, the three images red, orange, and yellow are superposed, and a colour corresponding to the combination of these will be produced. In fine, the colours which are superposed between every successive division of the upper and lower edges of the combined images are as follows, where the prismatic colours are designated by the capital letters, and their mixture or superposition by the sign +:

Between *a a* and *b b*	R
,, *b b* ,, *c c*	R + O
,, *c c* ,, *d d*	R + O + Y
,, *d d* ,, *e e*	R + O + Y + G
,, *e e* ,, *f f*	R + O + Y + G + B
,, *f f* ,, *g g*	R + O + Y + G + B + I
,, *g g* ,, *m m*	R + O + Y + G + B + I + V = W.

Thus it appears that the space between *g g* the bottom of the violet image and the top *m m* of the red image is coloured with a white light, because in this space all the seven images are superposed.

In the space between *g g*, the bottom of the violet image, and *f f*, the bottom of the dark blue image, there is a space which is illuminated by all the prismatic colours except the violet, and this space consequently approaches so near a white as to be scarcely distinguishable from it. The space between *f f*, the bottom of the dark blue image, and *e e*, the bottom of the light blue image, is illuminated by all the colours except the dark blue and indigo, and it consequently has a yellowish tint. The succeeding divisions downwards towards *a a* become more and more red until they attain the pure prismatic red of the lowest division. The colours of the upper extremity of the image may in like manner be shown to be as follows.

Between *s s* and *r r*	V
,, *r r* ,, *q q*	V + I
,, *q q* ,, *p p*	V + I + B
,, *p p* ,, *o o*	V + I + B + G
,, *o o* ,, *n n*	V + I + B + G + Y
,, *n n* ,, *m m*	V + I + B + G + Y + O
,, *m m* ,, *g g*	V + I + B + G + Y + O + R = W.

Thus it appears that the highest fringe at the upper edge is violet, that those which succeed it are formed by the mixture of violet and blue, to which green and yellow are successively added, until the colours become so completely combined that the fringe is scarcely distinguishable from a pure white. It is evident, therefore, that at the lower extremity the reds, and at the upper the blues, prevail.

If the object A A M M viewed through the prism be not white, then the preceding conclusions must be modified according to the analysis of its colour. Thus, if its colour be a green, it may be either a pure homogeneous green, or one formed by the combination of blue and yellow or other prismatic tints. In the former case, the prism will exhibit the object without fringes, but in the latter it will be fringed according to the composition of its colour, determined by the same principles as those which have been applied to the object A A M M.

28. In all that precedes it has been assumed that the light composing each part of the prismatic spectrum is simple and homogeneous. This conclusion, deduced by Newton, and adopted generally by all physical investigators since his time, is based on the assumption, that light which, being refracted by transparent media, cannot be resolved into parts differently refrangible, is simple and homogeneous.

Sir David Brewster, has, however, published the results of a series of observations, from which it would follow, that a pencil of light which does not consist of parts differently refrangible, may, nevertheless, be resolved into parts which have different colours; in other words that the light of certain parts of the spectrum, such, for example, as orange and green, although simple so far as respects refraction, is compound so far as respects colour. Thus, the orange light may be resolved into two lights equally refrangible, but differing in colour, one being red and the other yellow; and the green light may in like manner be resolved into two equally refrangible, one being yellow and the other blue.

29. In a word, the observations and experiments of Sir David Brewster have led him to the conclusion that the prismatic spectrum consists in reality of three spectra of nearly equal length, each of uniform colour, superposed one upon another; and that the colours which the actual spectrum exhibit arise from the mixture of the uniform colours of these three spectra superposed. The colours of these three elementary spectra, according to Sir David Brewster, are red, yellow, and blue. He shows that by the combination of these three, not only all the colours exhibited in the prismatic spectrum may be reproduced, but that their combination also produces white light. He contends, therefore, that the white light of the sun consists not of seven, but of three constituent lights, red, yellow, and blue.

This conclusion is established by showing that there is another method by which light may be resolved into its components, besides the method of refraction by prisms. In passing through certain coloured media, it is admitted that a portion of the light incident is intercepted at the surface upon which it is incident, and in its passage through the medium a part only is transmitted.

Now, this property of colours is taken by Sir David Brewster as another method, independently of refraction, of decomposing colours. He assumes that such a medium resolves the light incident upon it into two parts; first, the part which it transmits; and, secondly, the part which it intercepts. He concludes that these two parts are complementary, that is to say, that each contains what the other wants to make up white solar light; or, more generally, that the incident light, whatever be its nature, must be assumed to be a compound, consisting of the light transmitted and the light intercepted.

This being assumed, let a coloured medium, such as a plate of blue glass, be held between the eye and the spectrum. Certain colours of the spectrum will be transmitted and others intercepted. If the colours of the spectrum be simple and homogeneous light, such as they are assumed to be in the Newtonian theory of the decomposition of light, then the consequence would be that the appearance of the spectrum seen through the coloured medium would consist of dark and coloured spots; those simple lights intercepted by the glass appearing dark, and those transmitted by the glass having their proper colour. For if each colour of the prism be, as is assumed in the chromatic theory, simple, then the plate of glass can make no change in its colour by transmission.

It must therefore be wholly transmitted, partly transmitted, or wholly intercepted. If it be wholly transmitted, no change will be made, therefore, in its colour or intensity; if it be partly transmitted, its colour will remain the same, but its intensity will be diminished; if it be wholly intercepted, the space it occupied on the spectrum will be black. But these are not the effects, as Sir David Brewster states, which are observed. He finds, on the other hand, that the coloured spaces on the spectrum are not merely diminished in intensity, but actually changed in colour. Now, if any space of the spectrum be changed in colour, it follows from what has been stated, that the light transmitted must be a constituent of the colour of that space, to which the light intercepted being added, they would reproduce the colour of the spectrum. By such an experiment as this, Sir David Brewster found that the parts of the spectrum occupied by the orange and green lights produced yellow, from which he inferred that the glass intercepted the red, which combined with the yellow produced orange, and the blue, which combined with the yellow produced green. But if the glass have the power of thus intercepting the red and blue light, it might be expected that the red and the blue spaces of the spectrum would appear dark. He accordingly found that the light of the middle of the red space was almost entirely absorbed, as was also a considerable part of the blue space.

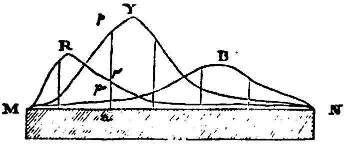
From experiments like these, which he made in great number, and under various conditions, Sir David Brewster deduced the conclusion to which we have adverted above.

He inferred that at a point of the spectrum, red, yellow, and blue light are combined in various proportions, the colour of each part being determined by the proportional intensities of these three colours in the mixture. In the red space, the proportions of blue and yellow are exactly those necessary to produce white light, but the red is in excess; a portion of it combined with the blue and yellow produces a white light, which is reddened by the surplusage of red. In the same manner, in the yellow space, the proportion of blue and red is that which is proper to white light, but there is a greater than the just proportion of yellow.

A part of this combining with the blue and red produces white light, which is rendered yellow by the surplus. In the same manner exactly, the blue space is shown to consist of a surplusage of blue, combined with the proportion of red and yellow, and the remainder of the blue necessary for whiteness. The other colours of the spectrum, according to Sir David Brewster, are secondary, or the result of combinations of red, yellow, and blue.

The means by which these three primary colours produce the tints of the spectrum may be more clearly understood by reference to fig. 16, wherein M N represents the prismatic spectrum with its usual tints. The curve M R N represents the varying intensity of the red spectrum, M Y N that of the yellow, and M B N that of the blue spectrum. The distance of each part of these curves respectively from M N is understood to be proportional to the intensity of the colour of that part, and the relative lengths of the perpendicular included within each curve represents the proportion of the intensities of the combined colours. Thus, at the point *p*, the three colours are mixed in the proportion of the lengths of the perpendiculars *p n*, *p′ n*, *p″ n*, the first representing the proportion of yellow, the second red, and the third blue; the red and yellow predominating, the colour at this point will be orange.

Fig. 16.



These observations and experiments, and the conclusions deduced from them by Sir David Brewster, have been now before the scientific world for more than twenty years. The experiments do not appear to have been repeated, nor the chromatic doctrine inferred from them to have been yet generally assented to or adopted. The chromatic analysis of Newton is the only theory advanced by physical authors.

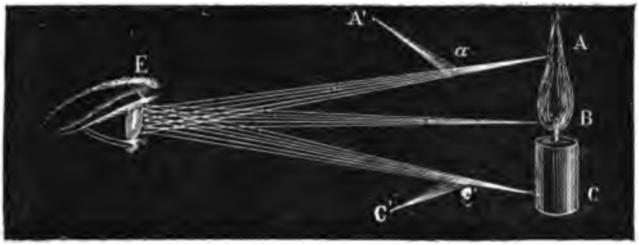


Fig. 1.

OPTICAL IMAGES.

CHAPTER I.

1. Great importance of the subject in relation to all the effects of vision.—2. Explanation of how an object is seen with the naked eye.—3. Images produced by plane reflectors.—4. How rays are reflected from such surfaces.—5. Experimental verifications of this.—6. Image of a point in a plane reflecting surface.—7. Image of an object in the same.—8. Real and imaginary images.—9. Images produced by spherical reflectors.—10. By a concave reflector.—11. Experimental verification.—12. Variation of position, and magnitude of image.—13. Images in convex reflectors.—14. Images produced by transparent bodies.—15. Refraction.—16. Cases in which light will not enter a transparent body.—17. Reflection of objects in water.—18. The fallacy of the fable of "the Dog and the Shadow."—19. Objects seen at the bottom of a transparent body.—20. Case of water and glass.—21. Broken appearance of a rod immersed in water.—22. Cases in which rays cannot emerge from a transparent body.—23. Experimental verification.—24. Reflection by a rectangular Prism.—25. Images produced by lenses.—26. Six kinds of lenses.—27. The axis of a lens.—28. Example of each kind of lens.—29. Optical image produced by a convex lens.—30. Relative position of the object and image.

1. THE images of visible objects produced by reflection from smooth or polished surfaces, natural and artificial, and by looking through transparent media, bounded by surfaces having certain curved shapes, play a part so important in the effects of vision, that it must be regarded as highly interesting to explain the optical principles upon which the production of such images depends, so far at least as may be necessary to render intelligible

the natural appearances and effects which are familiar to every eye, and innumerable contrivances, from which we derive essential benefit, either in repairing defects of vision, or extending the range of that sense to objects removed beyond its natural limits, either because of their minuteness or remoteness, or in fine in producing phenomena affording at once amusement and instruction.

The landscape seen inverted in the tranquil surface of the river or lake; the ship seen reproduced in like manner in the face of a calm sea; our persons, and the objects which surround us, seen in a looking-glass; the clear vision conferred on weak eyes by one sort of spectacle-glass, and the distinct vision conferred on strong but short-sighted eyes, by another; the apparent enlargement produced by magnifying glasses; the clear view of the scene and its personages afforded by the opera-glass; in fine, the marvellous world of minuteness opened to our view by the microscope, and the sublime spectacle of the remote regions of space, teeming with countless systems of suns and circumvolving worlds, displayed before us by the telescope, are a few, and only a few, of the innumerable things of wonder and interest, to comprehend which is impossible without some knowledge of the manner in which optical images are produced.

As we shall, from time to time, present all these interesting subjects in the pages of the "Museum," we propose now, as an indispensable preliminary, to explain with as much brevity as may be compatible with clearness, the principles upon which the natural and artificial production of optical images depends.

2. It is, in the first place, and above all things, necessary to understand the manner in which the eye obtains the perception of any visible object, because if we can show that precisely the same means are called into operation in the case of an optical image, we shall understand how the latter produces the same sensible impression as the object itself.

To comprehend this, then, it is necessary to consider that each point of a visible object is a focus from which rays of light diverge exactly as if the point were luminous. Some of these divergent rays are received by the eye, and enter it through the circular hole called the pupil,* and there produce a perception of the point of the object from which they have radiated. Since *each* point of the object is thus a distinct focus, or centre of radiation, a perception of each point, and therefore of the whole object, is thus produced.

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* See Tract on THE EYE, vol. v., pp. 54, 55.

This will be rendered more clear by reference to fig. 1. Let A, B, C, be a candle, for example, placed before the eye, E. Rays diverge from the top, A, of the flame, and enter the pupil. A cone of these rays, whose point is at A, and whose base is the pupil, enter the eye, and being collected on the retina, produce a perception of the point A.* And other cones, or PENCILS, as they are called, proceeding from the points B and C, and, in general, from all the points of the candle, radiate to the pupil in like manner, and severally produce perceptions, and so a perception of the candle is produced.

Now, if A, B, C, instead of being a real candle, were merely the optical image of a candle, the same perception of its presence would be produced, provided the same rays radiated in like manner from each point to the eye, and the observer would see it exactly as he would see the object itself, were it in the same position.

But it is not even necessary to the production of the perception that either the object or its image should be present, if the rays, no matter where they may have originated, or what route they may have followed, only enter the eye in the same lines of direction which they would have, had they come directly from the object. Thus, for example, if the pencils, instead of coming from A and C, had come from a similar point at A′ and C′ towards *a* and *c*, and had there by any optical agency been turned into the directions which they would have had, if they had come from A and C to the pupil, the perception produced by them would be exactly the same.

In fine, the perceptions produced depend on the directions which the rays have in entering the pupil, and are altogether independent of the route they may have followed before arriving there.

It will be most necessary that this fact be impressed on the memory, since the whole theory of vision, especially where optical agents are used, depends more or less upon it.

3. IMAGES PRODUCED BY PLANE REFLECTORS.

The most simple case of the production of optical images, and that of most frequent occurrence, is when they are produced by reflection from plane surfaces; as when a landscape and the firmament are seen reflected in the surface of water, or when objects are seen in a looking-glass.

To explain this very familiar phenomenon, it is necessary first

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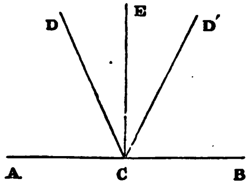
* See Tract on THE EYE, vol. v., pp. 54, 55.

to explain the manner in which rays of light are reflected when these fall on a plane surface.

4. The rays are reflected in this case exactly as an elastic ball is repelled when it encounters a hard and flat surface. Let C, fig. 2, be a point upon a reflecting surface A C, upon which a ray of light D C is incident. Draw the line C E perpendicular to the reflecting surface at C; the angle formed by this perpendicular, and the incident ray D C, is called the *angle of incidence.*

Fig. 2.



From the point C, draw a line C D′ in the plane of the angle of incidence D C E, and forming with the perpendicular C E an angle E C D′, equal to the angle of incidence, but lying on the other side of the perpendicular. This line C D′ will be the direction in which the ray will be reflected from the point C. The angle D′ C E is called the *angle of reflection.*

The plane of the angles of incidence and reflection which passes through the two rays C D and C D′, and through the perpendicular C E, and which is therefore at right angles to the reflecting surface, is called the *plane of reflection.*

This law of reflection from perfectly polished surfaces, which is of great importance in the theory of light and vision, is expressed as follows:—

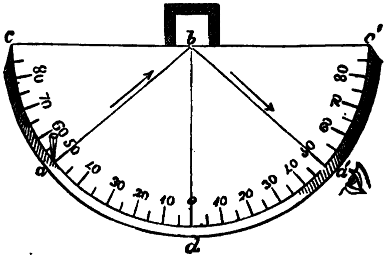
When light is reflected from a perfectly polished surface, the angle of incidence is equal to the angle of reflection, in the same plane with it, and on the opposite side of the perpendicular to the reflecting surface.

From this law it follows, that if a ray of light fall perpendicularly on a reflecting surface, it will be reflected back perpendicularly, and will return upon its path; for in this case, the angle of incidence and the angle of reflection being both nothing, the reflected and incident rays must both coincide with the perpendicular. If the point C be upon a concave or convex surface, the same conditions will prevail; the line C E, which is perpendicular to the surface, being then what is called in geometry, the normal.

5. This law of reflection may be experimentally verified as follows:—

Let *c d c′*, fig. 3, be a graduated semicircle, placed with its diameter *c c′* horizontal. Let a plumb-line *b d* be suspended from its centre *b*, and let the graduated arch be so adjusted that the plumb-line shall intersect it at the zero point of the division, the divisions being numbered from that point in each direction towards *c* and *c*′. Let a small reflector (a piece of looking-glass will answer the purpose) be placed upon the horizontal diameter at the centre with its reflecting surface downwards, and let any convenient and well-defined object be placed upon the graduated arch at any point, such as *a*, between *d* and *c*. Now, if the point *a*′ be taken upon the arch *d c* at a distance *d a*′ from *d* equal to *d a*, the eye placed at *a*′ and directed to *b* will perceive the object *a* as if it were placed in the direction *a*′ *b*. It follows, therefore, that the light issuing from the point of the object *a* in the direction *a b*, is reflected to the eye in the direction *b a*′. In this case, the angle *a b d* is the angle of incidence, and the angle *d b a*′ is the angle of reflection; and, whatever position may be given to the object *a*, it will be found that, in order to see it in the reflector *b*, the eye must be placed upon the arch *d c*′, at a distance from *d* equal to the distance at which the object is placed from *d* upon the arch *d c*.

Fig. 3.



The same principle may also be experimentally illustrated as follows:—

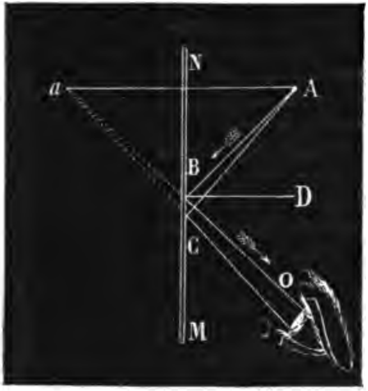
If a ray of sun-light admitted into a dark room through a small hole in a window-shutter strike upon the surface of a mirror, it will be reflected from it, and both the incident and reflected rays will be rendered visible by the particles of dust floating in the room. By comparing the direction of these two visible rays with the direction of the plane of the mirror and the position of the point of incidence, it will be found that the law of reflection which has been announced is verified.

6. This being premised, it will be easy to comprehend the manner in which images are produced by reflection from plane surfaces.

Let A, fig. 4, be any point of a visible object placed before a plane reflector, M N. Let A B and A C be two rays diverging from it, and reflected from B and C to an eye at O. After reflection, they will proceed as if they had issued from a point, *a*, as far behind the reflector as the point, A, is before it; that is to say, the distance A N will be equal to *a* N.

It is easy to verify this, by taking into account the law of reflection already explained. If B D be at right angles to M N, the angle, D B O, will be equal to B *a* N, and also to D B A, and consequently to B A N, from whence it follows that B A is equal to B *a*, and A N to *a* N: and since the same will be true of all rays which issue from A towards the reflector, it follows that, after reflection, all such rays will enter the eye, O, as if they had diverged from *a*.

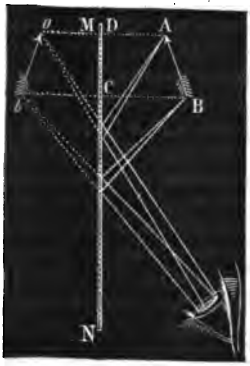
Fig. 4.



The eye O will therefore see the point A in the reflector as if it were at *a*.

7. But since the same will be true of each point in an object, A B (fig. 5), placed before the reflector, it follows that the rays which proceed from the several points of the object will, after reflection, enter the eye, as if they came from corresponding points of a similar object *a b*, placed just as far *behind* the reflector as the object itself A B is *before* it.

Fig. 5.



It is evident that in this case the image *a b* is not only similar to the object but precisely equal to it. Its position relatively to the reflector is similar to that of the object, but in an absolute sense it is different, as will be evident from observing that while the arrow A B points to the left, its image *a b* points to the right.

8. It will be perceived, that the reflected rays by which the perception of the image is produced, do not actually form the image. They enter the eye as if they actually came from the several points of such an image as the eye sees, but they do not come from such points. In such cases, where the image is perceived, but not actually produced, it is called a *virtual* or *imaginary image*. When the rays by which the image is perceived do actually diverge from the points of the image, the image is said to be REAL.

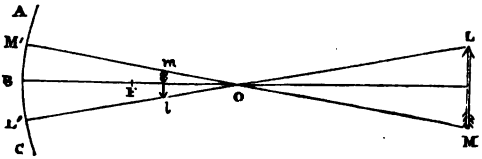
Since, in all the cases of reflection from plane mirrors, the rays diverge as if they had issued from points behind the mirror, the images are always virtual or imaginary.

9. IMAGES PRODUCED BY SPHERICAL REFLECTORS.

Curved reflecting surfaces may have various forms, but those which are most important are spherical; that is, such as consist of a part of the surface of a globe of greater or less diameter. A concave spherical reflector is a part of the surface of a globe seen from the inside, and a convex, seen from the outside.

10. Let A C (fig. 6) be the section of a concave reflector, whose centre is O. The line O B through the middle of the reflector and the centre, O, is called its axis. Let F be the middle point of the radius O B.

Fig. 6.



If an object be placed before the reflector at any place, such as L M, beyond its centre O, an image of this object *m l*, will be found at a certain point between F and O. The pencils of rays which radiate from each point of the object, after encountering the surface of the reflector, will be reflected, converging to the corresponding points of the image. Thus the rays which proceed from L will be reflected, converging to *l*, and those which proceed from M will be reflected, converging to *m*.

The image *m l* will therefore be inverted with relation to the object, the top of the one corresponding to the bottom of the other, the right to the left, and *vice versâ*.

It is evident also, that the linear dimensions of the image will bear to those of the object the exact proportion of their respective distances *m* O and M O from the centre of the reflector.

11. The production of such an image can be easily verified experimentally. Let the object L M be a candle, and let a small piece of card be held between O and F at right angles to O B. An image of the candle will be seen upon the side of the card presented to the reflector. The image will at first be nebulous and indistinct, but by moving the card alternately to and from the

centre O, a position will be found at which the image will be distinct. The card in this case should be so small as not to intercept too much of the light radiated from the candle to the mirror.

12. If the candle be now supposed to be gradually removed to greater and greater distances from the reflector, the image will approach nearer and nearer to the middle point F of the radius O B, and when its distance attains a certain limit, the image will be formed at F. However much the distance may be further augmented, the image will remain stationary at F.

This point F being therefore the place at which the images of all very distant objects are formed, is called the PRINCIPAL FOCUS of the reflector.

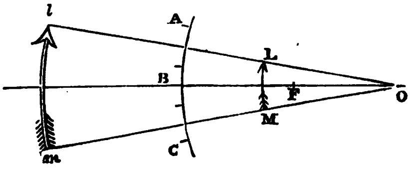
If the object L M be supposed to be moved continually towards the centre O, its image *l m* will also move towards O. When the object is moved past the point O towards the reflector, its image will be found outside the centre, so that if the object were *m l* the image would be L M. In passing the centre O, therefore, the object and image interchange places.

So long as the object is outside the centre, it will be greater than its image, but when inside the centre it will be less. The reflector, therefore, acts as a magnifier, or the contrary, according as the object is between O and F, or outside the centre O.

All these effects can be verified experimentally by receiving the image on a card in the manner described above. It is evident that in all these cases the images are real.

If the object L M be placed between F and B, as in fig. 7, the pencils of rays which diverge from the several points of the object will be reflected, diverging as if they had radiated from the corresponding points of an image, *l m*, at a certain distance behind the reflector. This image will be similar in position with the object, that is erect, and it will be greater than the object in its linear dimensions, in proportion to its distance from the centre O of the reflector.

Fig. 7.



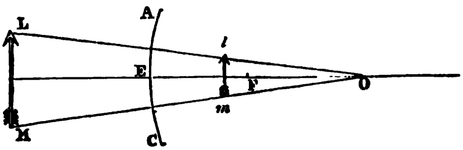
Since the image in this case is behind the reflector it will be imaginary.

If the object be moved towards B, the image will also move towards B, and if the object be moved towards F, the image will move from B, and will recede through spaces much greater than those through which the object is moved. In fine, when the object approaches to F, the image will recede indefinitely behind the reflector, and will disappear altogether when the object actually arrives at F.

All these phenomena admit of easy verification, by placing a candle in the several positions here assigned, and observing its image reflected in the mirror.

13. If the reflector be convex, the object L M (fig. 8), will have its image at the points *l m*, between the reflector and the principal focus F.

Fig. 8.



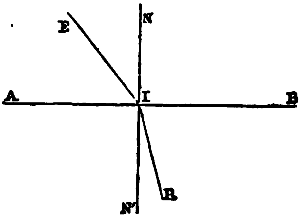
The rays proceeding from the several points of the object L M will, after reflection, diverge as if they had proceeded from the corresponding points of *l m*, and will produce upon the vision the same effects as if an object had been actually placed at *l m*.

The image in this case, therefore, will be erect, and it will be less than the object in the proportion of O *l* to O L. In this manner is explained the effect familiar to every one, that convex reflectors exhibit a diminished picture of the object placed before them.

14. IMAGES PRODUCED BY TRANSPARENT BODIES.

When light enters or issues from a transparent body its direction is deranged, its rays appearing to be broken at the points where they pass through the surface of the body. This effect is called refraction.

Fig. 9.



15. Thus, if the line A B (fig. 9) be supposed to represent the surface of such a body, and that a ray, E I, enter it at I, this ray, instead of preserving its direction, will be broken, as it were at I, and will take the direction I R. If the ray has been transmitted from R to I, it would, on issuing from the surface A B at I, have been broken, and would take the direction I E.

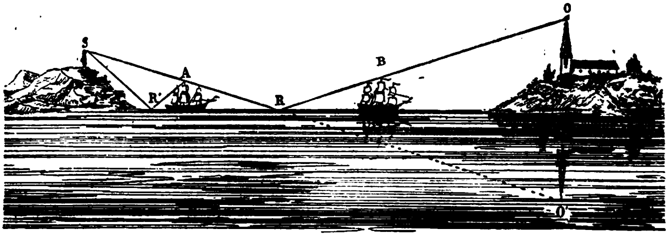
Let the line N N′ be drawn perpendicularly to the surface A B. If the ray E I be supposed to enter the surface at I, it will be always refracted *towards* the perpendicular I N′.

But if, leaving the direction R I, it issue from the surface at I, it will be refracted *from* the perpendicular I N in a direction such as I E. This is a law of refraction to which there is no exception.

16. Light will enter a transparent body whatever may be the obliquity with which it falls upon it; but it must be remembered that a certain proportion of it will be reflected. This proportion is very small, when the light strikes the body with very little obliquity, but it increases as the obliquity is increased, and is very considerable at great obliquities.

17. This will explain a phenomenon which is familiar to every eye. A spectator stationed on the banks of a river or lake, as at S, fig. 10, will see the opposite bank and objects such as O upon it, reflected in the surface of the water, and will see in the same way distant boats or vessels, such as B, reflected, the images being inverted according to what has been already explained (6, 7). But he will not see any reflection of a near object, such as A. In the case of distant objects, such as O and B, the rays O R, B R, which proceed from them striking the surface of the water very obliquely, the part of the light which is reflected in the direction R S is so considerable as to make a very sensible impression on the eye, although it is far from being as strong as a more complete reflection would produce, as is proved by the fact of which every one is conscious, that the images of objects thus reflected in water are far less intense and vivid than images would be reflected from the surface of a looking-glass.

Fig. 10.



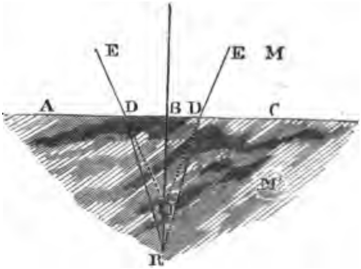
As for objects, such as A, placed near the spectator, they are not seen reflected, because the rays A R′, which proceed from them, strike the water with but little obliquity, and consequently the part of their light which is reflected in the direction R′ S towards the spectator is not sufficiently considerable to produce a sensible impression on the eye.

For this reason, also, a person on board a vessel may see plainly enough the banks or shores reflected in the water; but if he lean over the bulwark, and look down, he cannot see his own image.

18. In general, the illustrations and imagery of poetry, drawn from natural phenomena, are just and true. Yet this is not invariably the case. Every one will perceive from what has just been stated, that the fable of the Dog and the Shadow, which has been handed down through so many ages, diffused through so many languages, and taught so universally in the nursery and the school, is a most gross optical blunder.

19. If a visible object be placed below a transparent body, as, for example, at the bottom of a reservoir of water, or attached to the lower surface of a plate of glass, an observer above will see, not the object itself, but an optical image of it, which will be nearer to the surface, or less deep than the object. A reservoir of water, a river, or a lake, or the sea, when not too deep to allow the bottom to be visible, will on this account always appear to be less deep than it really is, because the optical image of the bottom, which is in fact what the observer sees, is less deep than the bottom itself. After what has been stated above, this is easily explained.

Fig. 11.



Let R (fig. 11) be a point of any object below the surface A C of any transparent body. The rays R D, which diverge from R, will, after emerging, be deflected *from* the perpendicular in the directions D E, and will enter the eye of an observer as if they came from I, a point less deep than R. The point R will, therefore, be seen as if it were at I, and the same being true of all the points of the object, it follows that an optical image of the object will be formed at a certain depth below the surface, less than the depth of the object.

This image will evidently be imaginary, since the rays by which it is produced diverge from the surface of the transparent body, but not from the points of the image.

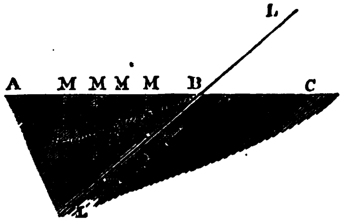
The greater the refracting power of the body is the more the rays D E, emerging from the surface, will be deflected from the perpendicular, and consequently the nearer the point I of their divergence, or, what is the same, the image, will be to the surface.

20. Thus, for example, if the transparent medium be water, the depth of the image will be about three-fourths of the depth of the object, and consequently water, when the bottom can be seen, always appears less deep than it is in the proportion of 3 to 4. A reservoir, whose real depth is 12 feet, will appear to have a depth of only 9 feet.

If the transparent body be glass, which has a greater refracting power than water, in the proportion of about 8 to 9, an object attached to the under-surface will appear to be at the depth of about two-thirds of the thickness of the glass.

21. If a rod L B L′, fig. 12, be plunged obliquely in water, it will appear as if it were broken at B, the part immersed being seen, not as it really is in the direction B L, but in the direction B *l*′. This will be easily understood, when it is considered that the image of such point of the rod will appear at a less depth than the point itself, in the proportion of 3 to 4. Thus the image of the several points P will be at the points *p*, the depths M *p* being severally three-fourths of the depths M P.

Fig. 12.



22. A certain part of the light which strikes upon the surface of a transparent body will enter it, no matter what be the obliquity with which it encounters it; but there is a certain obliquity beyond which light cannot emerge from it. Thus a ray of light proceeding from any object under water, which strikes the surface at an angle less than 41° 32′, cannot emerge, and in that case it may be asked, what becomes of the ray? The answer is, that it will be reflected back into the water exactly as if the surface were a perfectly polished plane surface.

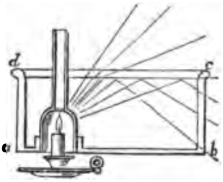
In the same manner, if the transparent body be glass, the ray cannot emerge from it, if the obliquity be less than 48° 11′, and in this case the ray will be reflected.

The reflection which takes place under such circumstances, is much more complete than any reflection from the surfaces of bodies, whether naturally smooth or artificially polished. It has, consequently, though somewhat improperly, been called PERFECT REFLECTION, for, although the reflection is incomparably more perfect than that from smooth or polished surfaces, nevertheless there is still a small part of the light lost.

The angle which limits the obliquity at which light can emerge from a transparent body, is called the limit of transmission.

23. This remarkable property of transparent bodies may be illustrated experimentally by the apparatus represented in fig. 13; let *a b c d* represent a glass vessel filled with water, or any other transparent liquid. In the bottom is inserted a glass receiver, open at the bottom, and having a tube such as a lamp-chimney carried upwards and continued above the surface of the liquid. If the flame of a lamp or candle be placed in this receiver, as represented in the figure, rays from it penetrating the liquid, and proceeding towards the surface *d c*, will strike this surface with various obliquities. Rays which strike it under angles of incidence within the limits of transmission will issue into the air above the surface of the liquid, while those which strike it at greater angles of incidence will be reflected, and will penetrate the sides of the glass vessel *b c*.

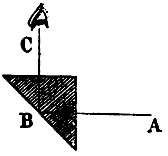
Fig. 13.



An eye placed outside *b c* will see the candle reflected on that part of the surface *d c*, upon which the rays fall at angles of incidence exceeding the limit of transmission; and an eye placed above the surface will see the flame, in the direction of the reflected rays, striking the surface with obliquities within the limit of transmission.

24. A remarkable property of glass prisms, which proves of great use in various optical instruments, depends on this property. Let B, fig. 14, be a rectangular prism, the longest face of which is inclined at angles of 45° to the two rectangular faces. If a ray of light, A B, enter one of the rectangular faces perpendicularly, it will pass into the glass without suffering any change of direction, and will encounter the surface B at an angle of 45°, which being less than 48° 11′, the minor limit of possible transmission, it will be reflected on issuing through the other rectangular surface perpendicularly, will meet the eye as it would if B were the only surface it had encountered, and the object from which the ray has proceeded, and whose real direction is B A, will be seen in the direction C B at right angles to B A.

Fig. 14.

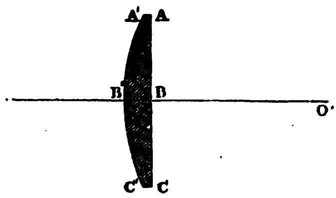


25. IMAGES PRODUCED BY LENSES.

A lens is a circular plate of glass, the surface of which is curved on one side or both.

26. A plano-convex lens, fig. 15, has one side, A C, flat, and the other convex.

Fig. 15.



A plano-concave lens, fig. 16, has one side, A' C', flat, and the other concave.

A double convex lens, fig. 17, has both sides convex, and a double concave lens, fig. 18, both sides concave.

It is not necessary that the convexities of the sides in the one, or the concavities in the other, should be equal. The degree of convexity or concavity will depend on the radius O B or O' B' of the sphere of which the lenticular surface is a part. The less that radius is, the greater will be the curvature of the surface. Thus, if O B be greater than O' B', the surface A' C' will be more convex (fig. 17), or more concave (fig. 18), than A C.

Fig. 16.

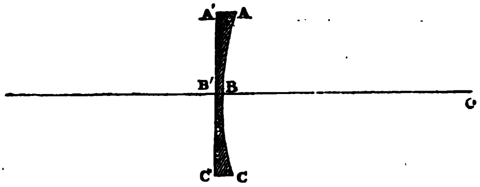
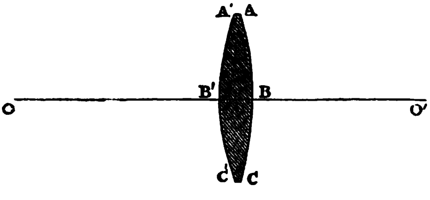


Fig. 17.



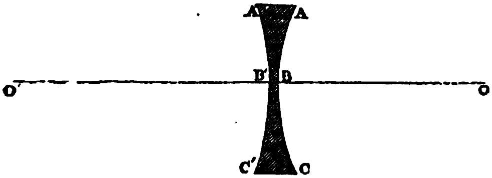
A concavo-convex lens has one side, A C, fig. 19, concave and the other convex, the concavity, however, being greater than the convexity.

A meniscus has also one side, A C, fig. 20, concave, and the other convex, but, on the contrary, the convexity is greater than the concavity.

27. A line, O O', which joins the centres of the two lenticular surfaces in figs. 17, 18, 19, and 20, and which passes through the centre of the lenses, and one which, in figs. 15 and 16, is drawn from the centre O at right angles to the flat surface, and passing through the centre of the lens, is called the AXIS OF THE LENS.

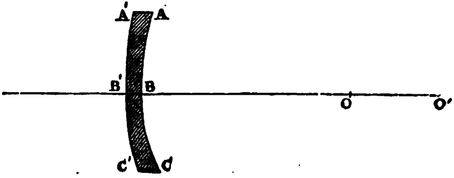
28. Examples of each of these forms of lenses are more or less familiar to every one. Thus the glasses of spectacles used by weak-sighted or aged persons, are usually double convex lenses. Those used by short-sighted persons are generally double concave lenses.

Fig. 18.



Spectacles called periscopic are sometimes used. The glasses of these, which are suited to weak sight, are meniscus, and those adapted to short sight are concavo-convex lenses.

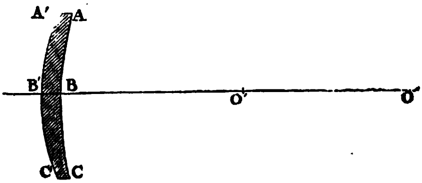
Fig. 19.



The eye-glasses of opera-glasses are usually double concave lenses. The object glasses are generally plano-convex lenses, the plane side being turned inwards.

29. If an object such as O''', fig. 21, be placed before a convex lens, and at right angles to its axis, an image, I''', of it will be produced behind the lens, also at right angles to the axis, inverted in position in relation to the object, that is, the top of the image corresponding with the bottom of the object, and the right side with the left, and *vice versâ*.

Fig. 20.

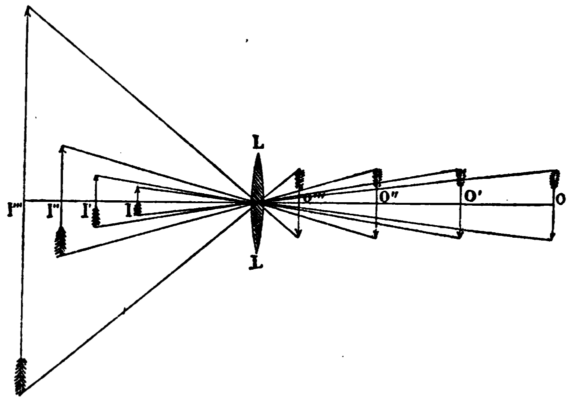


If the object be placed near the lens, the image will be formed at a great distance from it, and will be greater than the object in its linear dimensions in the same proportion as its distance is greater than that of the object from the lens.

This will be evident by inspecting the figure. The length of the image, I''', is evidently greater than that of the object, O''', in the same proportion as that in which the distance I‴L is greater than O‴L.

If we suppose the object O‴ to be gradually removed from the lens, so as to assume successively the positions O″, O′, &c., the image will gradually approach the lens, assuming successively the positions I″, I′, &c., and the linear dimensions of the object and image being still in the proportion of their distances from the lens, the image will necessarily decrease as the distance of the object from the lens increases.

Fig. 21.



30. Now, it might be imagined that by removing the object to distances increased without limit, the distance of the image from the lens would be decreased without limit. This, however, is not the case. While the object recedes through great spaces, its image approaches the lens through very small spaces, and when the object has been removed to a certain distance, the image is found to become sensibly stationary, not being capable of approaching nearer to the lens than a certain minor limit of distance, even though the distance of the object should be augmented indefinitely.

Fig. 22.

OPTICAL IMAGES.

CHAPTER II.

31. Experimental verification. — 32. Variation of the magnitude of the image.—33. Principal focus and focal length.—34. Variation of position, and magnitude of image.—35. When images real, and when imaginary. — 36. Images produced by concave lenses. 37. Focal length varies with refracting power.—38. Refracting power depends on material of lens.—39. Spherical aberration.—40. Images produced by lenses not absolutely clear and distinct.—41. Series of images.—42. Nebulous and confused effect.—43. Spherical aberration greater near the borders. —44. Increases with the curvature. —45. And with the magnifying power.—46. Spherical distortion.—47. Curved images.—48. How to diminish spherical aberration.—49. Lenses made from diamonds and other precious stones.—50. Ineffectual attempts at improvement by this means.—51. Methods of diminishing spherical aberration by proper adaptation of curvatures.—52. Aplanatic lenses.—53. Chromatic aberration.—54. White light compound.—55. Coloured lights sometimes compound.—56. Images produced by homogeneous lights.—57. Images produced by compound light.—58. Lenses always produce several images of a natural object.—59. Why they are not always so confused as to be useless for vision.—60. Dispersion.—61. Dispersion increases with refraction.—62. Dispersion different with different material.

31. This remarkable property of lenses, which is of the most extreme importance, not only in the theory and practical construction and application of microscopes, but of all optical instruments whatsoever, admits of the easiest and most simple experimental verification.

Take any magnifying glass (the object lens unscrewed from an opera glass, or the spectacle glass, or eye-glass of a weak-sighted person will answer the purpose), and holding it with its surfaces vertical, let the flame of a candle be placed near it in its axis, and let a white card be held behind it at right angles to its axis. Let the card be moved gradually from the glass until the inverted image of the flame of the candle is seen distinctly upon it. In this position the flame may be supposed to be the object O‴, and its image on the card the image I‴. Let the candle be now removed a little farther from the glass. The image will become indistinct, but if the card be removed a little towards the glass, its distinctness will be restored. The flame will now represent O″, and its image on the card I″. See fig. 22, p. 97.

In the same manner, if the candle be continually removed from the glass, its image will approach continually to the glass, but at a slower and slower rate. When, however, the flame has been withdrawn to the distance of several yards from the magnifying glass, its image will become sensibly stationary, never approaching in any perceptible degree closer to the glass, however far the candle may be removed.

32. It must be observed, nevertheless, that although the *position* of the image of the flame remains thus unchanged by the increased distance of the candle from the glass, its *magnitude* undergoes a very perceptible change, decreasing in linear dimensions in exactly the same proportion as the distance of the candle from the lens increases.

It appears, then, in fine, that when a convex lens is presented to any object, whose distance from it exceeds a certain limit, the optical image of such object will be formed at a fixed distance behind the lens, which distance will be the same whatever the distance of the object may be. Thus, for example, if the lens be presented to a window looking out over a landscape, the image of this landscape will be seen depicted, but inverted in position on a card held behind the lens, at the fixed distance from it, which has just been indicated; and although the trees, buildings, and mountains, which form the view before the lens, are at extremely various distances, their images will be all depicted on the card upon a small scale, at precisely the same distance from the lens.

33. The point in the axis of a lens, at which a distinct picture of distant objects is thus produced, is called the PRINCIPAL FOCUS * of the lens, and the distance of this point measured upon the axis from the lens is called the FOCAL LENGTH of the lens.

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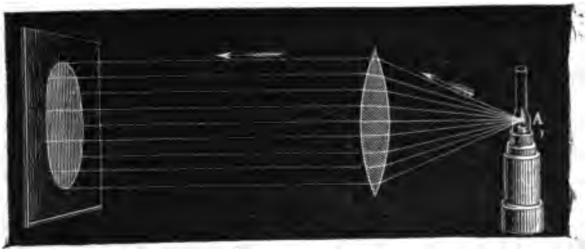
* In some practical works on the microscope, this point is called the SIDEREAL or SOLAR focus. This term has not, however, obtained a place in the nomenclature of scientific writers.

If a radiant point be placed at A, fig. 23, at the principal focus of a lens, the rays diverging from it after passing through the lens will be rendered parallel, as may be shown experimentally by receiving them upon a screen as indicated in the figure. An illuminated disc will be produced upon the screen equal in size to the lens.

Fig. 23.



34. Having explained the change of position which the image undergoes by removing the object indefinitely *from* the lens, let us now consider how its position will be affected if the object be moved indefinitely *towards* the lens.

It is evident, from what has been already explained, that when a very distant object approaches the lens, no change whatever in the *position* of its image is at first produced, the image remaining always at the principal focus, but the *magnitude* of the image will be sensibly augmented, its linear dimensions increasing in exactly the same proportion as the distance of the object from the lens decreases.

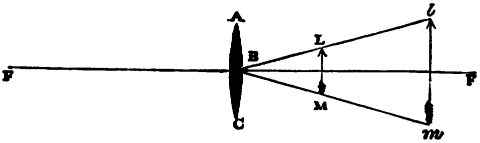
When, however, the object has approached within a certain limit of distance, the image will begin, at first very slowly, and afterwards more rapidly, to recede from the lens. It will thus continue to recede, and at the same time to increase in its dimensions, until the object is brought to a distance from the lens equal to its focal length. The image having then augmented indefinitely in magnitude and distance, will altogether disappear.

This is, therefore, an exceptional position of the object, in which no optical image is produced by the lens.

If we suppose the object to be brought still nearer to the lens than its focal distance, no actual optical image will be produced, but the rays of light which, having issued from the various points of the object, pass through the lens, will be refracted by it into directions such as they would have had if they had issued from a similar object at a greater distance in front of the lens, and of proportionally greater dimensions.

To render this more clear, let A C, fig. 24, represent a convex lens, whose focal length is B F, and let L M be an object placed before it at a less distance than B F. Now, it will be understood that from every point of the object L M, rays of light diverge, which, passing through the lens A B, have their directions changed by it, and this change is such that, instead of diverging from the various points of the object L M, they will diverge from a similar series of points placed at a greater distance before the lens. In fine, after passing through the lens, they will diverge as if they had issued from the points of an object *l m* in all respects similar to the object L M itself, and having a like position, but greater than the object in its linear dimensions, in the proportion of *l* B to L B; that is, of its distance from the lens to the distance of the object from the lens.

Fig. 24.



In this case, then, no actual optical image is produced which, as in the former case, can be received and exhibited upon a card. But if the eye of an observer be placed behind the lens, it will receive the rays proceeding from the object L M, and passing through the lens exactly as if they really had proceeded from the object *l m*, without the interposition of a lens, and the eye will be affected, and vision produced exactly as if such an object as *l m* were present.

35. When the optical image is actually formed, so that it can be received and exhibited upon a card or screen, it is said to be a REAL IMAGE; and when it is formed in the manner above described, so as to be seen by the eye directly receiving the rays from the lens, but not capable of being formed on a screen, it is said to be IMAGINARY.

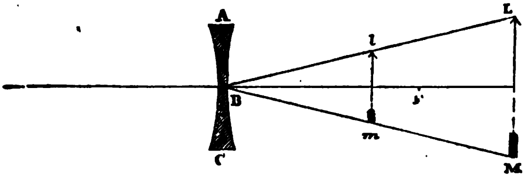
An exception might be taken to the terms, inasmuch as the visual image is as real in the one case as in the other. They have, however, been generally adopted in the nomenclature of optics.

All that has been said of the optical images, real and imaginary, produced by double-convex lenses, and of their principal foci, will be equally applicable to plano-convex and meniscus lenses. In each of these the convexity being the prevalent character, their optical effects are similar to those of double-convex lenses, subject, nevertheless, to some qualifications which will be explained hereafter.

36. The optical effect of a concave is, as might be expected, the reverse of that of a convex lens. In no position can a concave lens produce a real optical image.

Let A C, fig. 25, be such a lens, and L M an object placed anywhere before it. The rays which diverge from the various points of L M will, after passing through the lens, diverge as if they had issued from the corresponding points of a similar object *l m*, nearer to the lens; and an eye placed behind the lens will see the object, not as it is at L M, but as it would be if placed at *l m*, and reduced to a lesser magnitude.

Fig. 25.



This explains a fact which must be familiar to every one who may have looked through concave glasses, such for example as the spectacles of short-sighted persons. All objects seen through them appear to be diminished.

37. The focal length of a lens depends on the degree of refraction which it is capable of producing on the rays which pass through it. The greater this refraction is the more the convergence of the rays will be increased, and the less will be the focal length.

The refracting power of a lens depends partly on its form, and partly on the material of which it is made. With a given material the refracting power will increase with the convexity. The more convex the surfaces are the greater will be the refracting power, and the less the focal length and the nearer to the lens will the image of an object at a given distance be produced, the lens being supposed to be convex.

38. But the refracting power, and therefore the focal length, also depends on the material of the lens. Two lenses having the same convexity will have different refracting powers, and therefore different focal lengths, if they are made of different transparent bodies, or even of different sorts of the same substance. A lens of water will have a longer focus than a similar one of glass; and the latter will have a longer focus than a similar one made from a diamond, because water has a less refracting power than glass, and glass less than diamond. In the same way, a

lens of crown-glass will have a longer focus than a similar one of flint-glass, since the latter has a greater refracting power than the former.

39. SPHERICAL ABERRATION.

In all that has been stated hitherto, it has been assumed that the images produced by lenses are as perfect reproductions of the object as is the image produced by a common looking-glass.

In practice this conclusion requires considerable qualification.

In the first place, lenses, of whatever material they may be formed, though very transparent are not absolutely so, and they consequently intercept more or less of the light which falls upon them. The thicker they are the greater is the quantity of light thus intercepted. Sometimes there is a tendency to intercept light of a particular tint of colour. In such cases the brightness of the image is not only deteriorated, but it is falsely coloured, being most tinged with those colours which the material of the lens transmits most freely.

Although such imperfections cannot be totally removed, they may be and have been reduced to so very inconsiderable an amount by the proper selection and adaptation of the material of which lenses are formed, that they need not be farther noticed here.

The loss of light by reflectors, however highly polished the reflecting surface may be, greatly exceeds the amount of light intercepted by transparent media. On this, as well as some other accounts, refracting have been generally preferred to reflecting microscopes.

40. Although the image of an object produced by a convex lens in the manner already described (29), appears at first view to be an exact reproduction of the object, it is found, when submitted to rigorous examination, to be more or less confused and indistinct. This confusion is augmented in proportion as it is more magnified, and when it is viewed as in a compound microscope, with a simple microscope so as to be still further amplified, the confusion becomes so great as to deprive the observation of all utility.

This indistinctness and confusion arises from two causes, one depending on the form, and the other on the material of the lens.

That which depends on the form of the lens we shall now explain.

41. If a convex lens be presented to a visible object, the central part being covered by a disc of card, leaving uncovered a ring of surface at the borders, a distinct, but very faintly illuminated

image will be produced at a certain distance from the lens. Let this distance be called d'.

If the border of the lens be now covered with a ring of card, and the central part with a card disc less in diameter than the ring, so as to leave an uncovered space between the disc and the ring, another faint but distinct image will be produced at a certain distance d'', a little greater than d'.

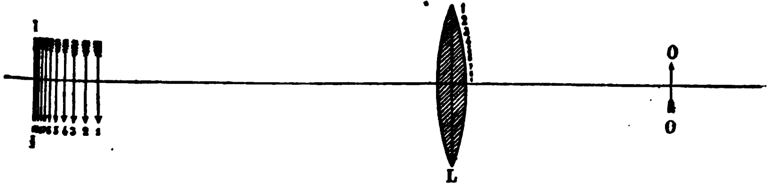
If the border be covered with a broader ring of card, and the central part by a still less disc, so as to leave an uncovered ring of surface smaller than the last, another image will be produced still faint and distinct, and at a distance d''' greater still than d''.

In fine, by continuing this process, it will be found that if the lens be resolved into a series of annular surfaces, concentric with each other and with the lens, a series of images will be produced at distances d', d'', d''', d'''', &c., gradually increasing, that produced by the external annulus being at the least distance, and that produced by the spot surrounding the centre at the greatest distance.

On comparing the series of distances d', d'', d''', d'''' . . . . at which these images are placed, a very important circumstance will be observed in their distribution. It will be found that while those produced by the central annuli are crowded very closely together, those produced by the annuli near the edge of the lens are separated one from another by much more sensible spaces.

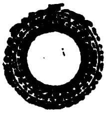
When the entire surface of the lens is uncovered and exposed at once to the object, it is evident that this series of images will be produced simultaneously. Some idea of their distribution along the axis of the lens may be found by referring to fig. 26.

Fig. 26.



The object being O O, and the image produced by the small central spot of lenticular surface being at I I, the images formed by the rings of surface immediately contiguous to this spot will be crowded together so closely in front of a screen held at I I, that they will all be formed upon the screen with very little less distinctness than the image formed by the central spot itself, so that by their superposition upon the screen, all will contribute to augment the brightness of the image formed upon it, without producing injurious confusion or indistinctness. But not so with the much more distant and more widely separated images 1, 2, 3, 4, &c., produced by the exterior rings of the lenticular surface. These being at very sensible distances from the screen held at the place of the central image would produce a confused, cloudy, and indistinct picture on the screen, which falling upon the more distinct picture produced by the central part, would give the whole a nebulous and misty appearance, such as is shown in fig. 27, when the object is a circular disc.

Fig. 27.



42. It appears therefore that a distinct optical image of an object placed before a convex lens can only be formed when a certain limited part of the central lenticular surface is exposed to the object. The exterior part would render the image brighter by means of the increased light transmitted to it, but at the same time confused by reason of the distance of the place of the distinct image formed by the borders from that formed by the centre.

The confusion and indistinctness produced in the optical image of an object from the cause here explained and illustrated is called the SPHERICAL ABERRATION.

43. From what has been explained, it appears that the aberration produced by the central part of the lens is inconsiderable, but that it increases rapidly towards the borders. The extent of the central surface, which is thus free from any considerable aberration depends on the convexity of the lens. If it be but slightly convex, or what is the same, if the radius of the sphere of which it forms a part be great, the extent of this central surface will be considerable; but as the lens becomes more and more convex, or what is the same, as the radius of the sphere of which it forms a part is less and less, the central part exempt from injurious aberration also becomes less and less.

44. It follows from this, that in proportion as lenses are more convex, their diameters must be less, inasmuch as otherwise the aberration produced by external parts of their surfaces would destroy the clearness and distinctness of the image.

Since every increase of the magnifying powers of a lens formed of a given material requires an increase of its convexity, it will also render necessary a decrease of its diameter.

45. If while the diameter is thus decreased the focal length remained the same, the aperture and consequently the illumination of the image would be diminished. But while the increased

convexity renders a diminished diameter necessary it also produces a diminished focal distance; and since the aperture (that is, the angle formed by lines drawn from the principal focus to the extremities of a diameter of the lens) increases with the decrease of the focal distance, this decrease may compensate for the decrease of the diameter, so that the aperture may not be diminished. But in fact the decrease of focal distance, much more than compensates for the decrease of the diameter, and in good lenses the aperture is much greater for small lenses of high magnifying power, than for larger ones with lower magnifying power.

It is owing to this, that great magnifying powers can be obtained without rendering the illumination of the image injuriously faint, as it would be, unless the aperture of the lens on which it depends were augmented in some degree proportionate to the increase of the power.

46. SPHERICAL DISTORTION.

Independently of the spherical aberration properly so called, there is another optical effect produced in the image, depending on the form of the lens, which requires notice.

In the preceding paragraphs it has been assumed that the *form* of the image is that of the object, and when the image is small this may be considered as practically true. But when the image is considerably amplified the form differs sensibly from that of the object.

If an object which is straight or flat be presented to a convex lens, outside its principal focus, so that a real image shall be produced on the other side of the lens, the image will not be flat but curved, with its concavity towards the lens. If the object were curved with its convexity towards the lens, its image would be also curved, but with its concavity towards the lens, and the curvature of the image would in that case be greater than that of the object.

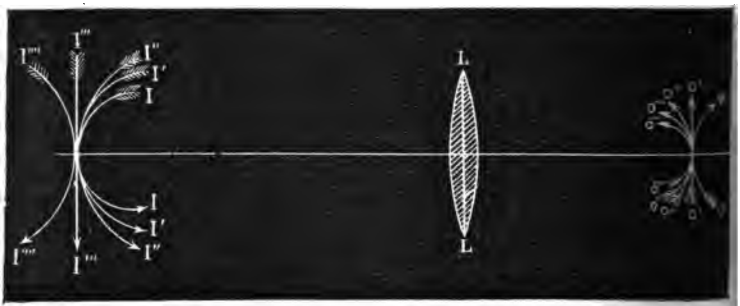
If the object were concave towards the lens, its image would be also concave towards the lens, but with less curvature than the object.

47. If the curvature of the object be supposed gradually to increase, the concavity still being presented towards the lens, the image will be also concave towards the lens, but its curvature will diminish as that of the object increases, and when the curvature of the object increases to a certain point, the image will become straight or flat.

If the curvature of the object still continue to increase, the image will become convex towards the lens, and its curvature will increase with that of the object.

The relative forms of the object and its image in such case will be more clearly understood by reference to fig. 28, where L L is

Fig. 28.



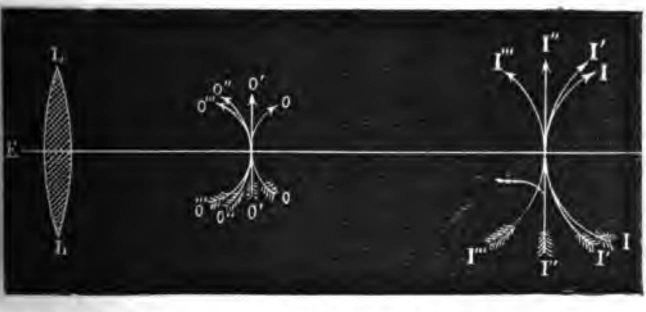
the lens, and O O, O′ O′, O″ O″, O‴ O‴, and O⁗ O⁗, objects having the different forms above mentioned, placed at a point beyond its principal focus. The images of these severally are indicated by the letters I I, I′ I′, I″ I″, I‴ I‴, and I⁗ I⁗, at the other side of the lens. Thus the image of the straight or flat object O′ O′ is the curved image I′ I′, concave towards the lens L L. In like manner, I I, concave towards L L, is the image of the object O O, which is convex towards L L; I″ I″, concave towards L L is the image of O″ O″, also concave towards L L; while the flat image I‴ I‴ is that of the object O‴ O‴, which is curved and concave towards L L. The image I⁗ I⁗, convex towards L L, is that of O⁗ O⁗, concave towards L L.

It will be evident that none of these images could be projected with uniform distinctness upon a flat screen, except that of the curved object O‴ O‴, the image of which is flat. If the image of a flat object O′ O′ were projected upon a screen held at the point where its curved image I′ I′ intersects the axis of the lens, it would only be distinct at and near the centre. The screen being behind the extremities would be out of focus with them, and consequently those parts of the image would be indistinct. If the screen were advanced, so as to render the extremities distinct, the centre would be out of focus, and consequently indistinct.

In this case, the object is assumed to be placed beyond the focus of the lens, and consequently the image is always real, whatever be its form. Let us now consider the case in which the object is placed within the focus, and its image consequently imaginary (34).

Let L L, fig. 29, be the lens, and let the object, placed within its focus, be viewed by an eye at E, an imaginary image will be seen at a certain distance, greater than that of the object.

Fig. 29.



If the object be straight or flat, such as o′ o′, the image will be curved with its convexity turned towards the lens, as shown at I′ I′, in the figure. If the object be concave towards the lens, the image will be less and less convex, until the object having a certain concavity, such as o″ o″, the image will be straight or flat as shown at I″ I″. If the concavity towards the lens be still greater, as at o‴ o‴, the image will become concave towards the lens, but less so than the object. If the object be convex towards the lens, as at o o, the image I I will also be convex towards it.

It follows, therefore, that a straight or flat object seen through a convex lens thus will appear curved or convex, and that a convex object will appear more convex. A concave object, provided it have a certain degree of curvature, will have a straight or flat image, and all objects more concave will have concave images.

These results will be found to have considerable importance in the practical construction of compound microscopes.

48. From what has been explained it follows, that if any expedient could be discovered, by which the focal length of a lens could be shortened without increasing its convexity, we could obtain a given magnifying power with a lens of a given diameter without increasing the aberration, a result which would be a most evident advantage. Now, there is only one way by which this could be accomplished, which is by finding some material for the lens, which without any countervailing disadvantages would have a greater refracting power than glass. A lens made of such a material would have a shorter focus, and consequently a greater magnifying power than a lens of glass with the same convexity.

49. Several transparent substances having this important property are found among the precious stones, and more particularly in the diamond, which has a greater refracting power than any known transparent body.

This advantage, and some other optical properties, induced some scientific men, among whom Sir David Brewster held a conspicuous place, to cause lenses to be made of diamond, sapphire, ruby, and other precious stones, and sanguine hopes were entertained of vast improvements in microscopes, resulting from their substitution for glass lenses. These hopes have however proved delusive.

50. Notwithstanding all that enterprise, skill, and perseverance could accomplish, both on the part of scientific men, such as Sir David Brewster, and practical opticians, such as Pritchard and Charles Chevalier, the attempt has been abandoned. Independently of the cost of the material, difficulties almost insuperable arose from the heterogeneous nature of the gems. Their double refraction, and the imperfect transparency and colour of some of them. The improvement of simple microscopes composed of glass lenses by the invention of doublets, and by the proper combination and adaptation of their curvatures, was also such as to render their performance little, if at all inferior even to the gem lenses, while their cost is not much more than a twentieth of that of the latter.

In all cases, therefore, where objects or parts of objects of extreme minuteness are submitted to microscopic examination, requiring the application of high magnifying powers combined with extreme precision of definition, the compound microscope must be resorted to.

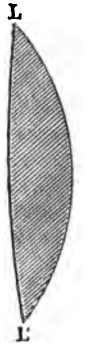
51. Although it is not possible to efface altogether the effects of spherical aberration, yet they have been so considerably diminished by the adaptation of the curvatures of the lenticular surfaces, that in well-constructed optical instruments they may be regarded as entirely removed for all practical purposes. This is accomplished by giving to the two sides of the lens different curvatures, so adapted that the aberration produced by one shall be more or less counteracted by the aberration produced by the other.

It has resulted from a mathematical analysis of the phenomena, that the lens which has least spherical aberration is double convex with unequal convexities, the radius of the flatter side being six times that of the more convex side. If the object to which such a lens be presented be very distant from it, and consequently the image proportionately close to it, the more convex side should be presented to the object. This, for example, is the case in all forms of telescopes and opera-glasses. But if, as is always the case in the microscope, the object be placed much nearer to the lens than its image, the flatter side of the lens should be presented to the object.

With such a lens the entire extent of the aberration, the object being distant, does not exceed its thickness by more than the 14th part. If the thickness of the lens be expressed by 1, the aberration for a distant object will be 1·07.

Such a lens is represented in fig. 30, and it will be evident in how slight a degree it differs from a plano-convex lens. It may therefore be expected that its aberration cannot differ much from that of the latter form of lens, which has the advantage of being much more easily worked. It is accordingly found by calculation that the aberration of a plano-convex exceeds that of a lens of the above form, in the proportion of 27 to 25, or something less than a twelfth.

Fig. 30.



If a plano-convex be used the flat side should be presented to the object if it be near, and the convex side if it be distant.

52. Lenses, or combinations of lens, which thus practically efface the effects of spherical aberration are said to be APLANATIC, from two Greek words α (a) and πλάνη (plánē), which signify *no straying*.

53. CHROMATIC ABERRATION.

It has been already shown in a former number of this "Museum," that solar light is a compound principle, consisting of several component lights differing one from another as well in colour as in their susceptibility of refraction, and that the colours of all natural objects arise from their peculiar properties of reflecting light, red objects being those which reflect red light, blue those which reflect blue light, and so on, a white object being one which reflects indifferently lights of all colours, and a black object one which reflects no light.

54. White light is composed of lights of various tints, varying from red to violet in the following order: red, orange, yellow, green, blue, indigo, and violet, each colour being less refrangible than that which follows it.

55. Coloured lights may be also more or less compounded; thus, various tints of orange may be produced by the combination of reds and yellows, tints of green by the combination of yellows and blues, and so on.*

56. This being understood, let us suppose an object illuminated

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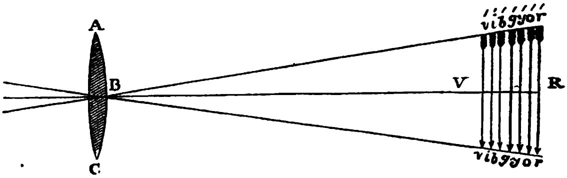
* See Tract on "Colour."

by a simple and homogeneous red light placed before a convex lens A C, fig. 31, and that an image of it is produced at *r r′*. Let the same object be now supposed to be illuminated by simple and homogeneous orange light. This light being more refrangible than red light, the lens A C will produce an image *o o′* of the object, a little nearer to it than *r r′*. If the object be next illuminated with simple and homogeneous yellow light which is still more refrangible, the image *y y′* will be produced at a still less distance from the lens, and in fine if the object be successively illuminated with simple green, blue, indigo and violet lights, the images will be produced successively at *g g′*, *b b′*, *i i′*, and *v v′*, nearer and nearer to the lens as the light is more refrangible.

Fig. 31.



57. If the object, instead of being illuminated as we have here supposed it to be by a simple homogeneous light, be illuminated by any light compounded of two or more simple lights, then so many distinct images of it will be produced at different distances from the lens, as there are simple lights in the compound, and these images will differ in colour from the object and from each other. Thus, for example, if the object be illuminated by a compound light of a green tint, composed of simple yellow and blue lights, two images of it will be produced, the nearer blue, and the more distant yellow.

A like consequence will follow if the object be illuminated by a compound light made up of three simple lights, when three images will be formed, and so on.

If then an object reflect from its surface the white solar light, which is a compound of all the colours, it will follow that all the coloured images which have been here produced in succession, will be produced at one and the same time, and will be placed one before the other in a regular series at unequal distances from the lens, as already described.

58. It has been shown* that the colours of natural objects generally are more or less compounded. It is only in very rare

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* See Tract on "Colour."

and exceptional cases that the light emitted or reflected by any body is pure homogeneous light. It follows, therefore, from what has been explained above, that as many distinct images of each object will be produced by a lens as there are distinct homogeneous colours which enter into the composition of the light it emits or reflects, and that these several images will be placed at several different distances from the lens corresponding with the different refrangibilities of the different homogeneous lights of which they are composed.

If different parts of the same object be differently coloured, different series of images of those parts will necessarily be produced at different distances from the lens, according to their several component colours.

59. From all this it might be inferred that the optical utility of lenses would be utterly destroyed in the case of all objects save such as would emit or reflect homogeneous light. For if such a multitude of variously coloured images be formed at various distances from the lens, the effect which would be produced upon a card held at any distance whatever, might be supposed to be a confused patch of coloured light, having no perceptible resemblance in form or colour to the object; and such would certainly be the case if the distances of the several images, one from another, were considerable. These distances, however, are so small, that the coloured images are so blended together that the decomposition of their colours appears principally by coloured fringes produced upon their edges, and in general upon the outlines of their parts. Nevertheless, when these false lights and fringes are magnified, as in the compound microscope they always are, by the eye-glass, the general appearance of the object under observation would be so changed as to colour, and so indistinct as to outline, as to be rendered useless for all the purposes of scientific enquiry.

The indistinctness of the image thus produced, is called chromatic aberration, from the Greek word χρωμα (chroma) signifying COLOUR.

60. The extent of the chromatic aberration produced by a lens measured by the interval V R (fig. 31) between the red and violet images, is called the DISPERSION of the lens.

The preceding observations have been applied only to the images produced by a convex lens, but they are equally applicable to concave lenses, taking into account that the images in the case of these last are imaginary. Thus, if a white object be placed before a concave lens, the light issuing from it, after passing through the lens, will proceed as if it had diverged from different objects, leaving the seven colours placed at different distances from the lens, but on the same side of it with the object, as explained in (36).

61. With the same lens the dispersion will increase with the refraction, and consequently the more the image is magnified the greater will be the dispersion and the aberration, and the more confused and indistinct the image.

62. It might naturally therefore be supposed that if two lenses made of different transparent substances produce images of the same object at the same distance from them, and consequently equally magnified, they would produce the same dispersion and aberration. It is found, however, that this is not the case. A lens of diamond and a lens of glass may be so formed that the same object being placed at equal distances from them, the distances at which the violet image will be produced shall be exactly equal, but the same equality will not prevail between the distances of the red image and those of the intermediate colours.

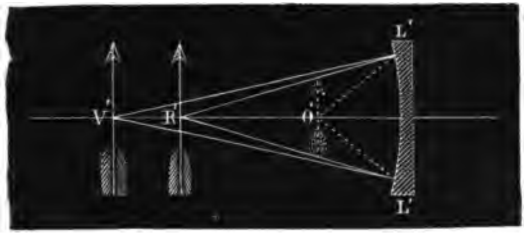


Fig. 36.

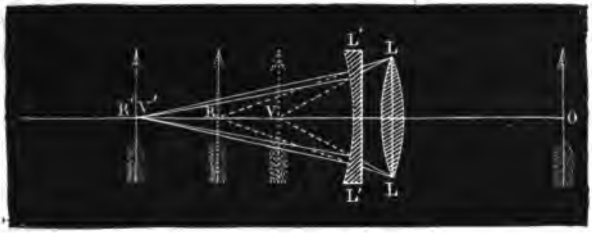


Fig. 37.

OPTICAL IMAGES.

CHAPTER III.

63. Experimental illustration.—64. Dispersive powers.—65. Dispersive power does not necessarily increase with refractive power.—66. Example of the diamond.—67. Achromatic lens.—68. Achromatic combination of flint and crown-glass.—69. Form of the compound lens.

63. To make this, which is a circumstance of the highest importance, more clear, let L L, fig. 32, and L' L', fig. 33, be two lenses, the former of diamond, and the latter of glass, and let O O and O' O' be a white object placed at the same distance before them. Let V be the violet, and R the red image, produced by the lens L L, the images of the intermediate colours being between V and R according to what has been explained above. Now let us suppose that such a convexity is given to the lens L' L', which is evidently always possible, that the distance of the violet image V' of O' O' from the lens L' L' shall be equal to that of the violet image V of O O from the lens L L. In that case, the distance of the red image R′, from L′ L′, will be greater than that of the red image R from L L, and in like manner the distances of all the intermediate images of O′ O′ from L′ L′ will be greater than those of the corresponding images from L L.

Thus the coloured images of O′ O′ produced by L′ L′ will be spread over a greater space than those of O O produced by L L. The dispersion of the latter is therefore greater than the dispersion of the former.

With the same amount of refraction, therefore, the lens L′ L′ produces more dispersion than the lens L L.

If we suppose the convexity of the lens L L to be increased, the refraction will be increased, the image V will be produced at a less distance from it, and at the same time the dispersion V R will be increased. The convexity, as shown at L″ L″ (fig. 34), may be so much increased, that the dispersion V″ R″ shall be equal to V′ R′.

Thus it appears that a diamond lens, which would have a dispersion equal to that of a glass lens, would have a much greater refraction, and would produce the image of the same object much closer to it. In a word, the focal length of a diamond lens having the same dispersion as a glass lens, would be much shorter than the focal length of the latter; or, what is the same, with an equal focal length, the diamond lens would have a less dispersion.

64. It appears, therefore, in general, that lenses made of different transparent substances will have, under like conditions, different dispersions. The DISPERSIVE POWERS of any two transparent media, will be measured by the dispersions which lenses of the same focal length made from them would produce.

The actual DISPERSION produced by a lens must not be confounded with the DISPERSIVE POWER of the material of which the lens is formed.

The actual *dispersion* produced by a lens of a given material, varies with its focal length, and with the distance of the object from it, so that with the same lens there may be many different quantities of dispersion, and the quantity will also be different with different lenses of the same material. But the *dispersive power* depends on the material alone, and is altogether independent of the form of the lens, its focal length, or the position of the object relatively to it. It will be most important that this distinction should be understood and remembered.

65. It might be imagined that the dispersive power would necessarily increase with the refractive power of the transparent body. On comparing together the optical effects of different media, no such correspondence is however found to prevail; on

the contrary, the bodies having nearly equal refractive powers, often have very unequal dispersive powers, and *vice versâ.*


Fig. 32.


Fig. 33.

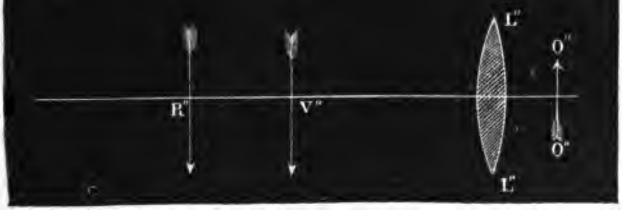


Fig. 34.

66. The high refracting power of the diamond, combined with its low dispersive power, were among the circumstances which raised the hopes already mentioned, that great improvements in microscopic lenses would result from the substitution of that gem and others, having like optical properties, for glass. Happily the invention of other and better expedients for surmounting the imperfections arising from chromatic aberration, have rendered unnecessary so expensive a remedy.

67. The discovery of the fact that the dispersive powers of different transparent bodies is not proportional to their refractive powers, but on the contrary, that bodies of greater refractive powers have sometimes lower dispersive powers, has supplied a remedy, which practically speaking, may be said to be completely efficacious for the removal of all the injurious effects of chromatic aberration. The manner in which this important end has been

attained, admits of an explanation, which after what has been stated above will be easily understood.

Let an object O O, fig. 35, be placed before a convex lens, C C, and let V be its violet, and R its red image, the dispersion being

Fig. 35.

consequently V R. Now, let F F be a concave lens, through which the rays proceeding from C C will be transmitted. This lens being concave, will have the effect of diminishing the convergency of the rays, and of throwing both the violet and red images to a greater distance; but it will have a greater effect on the violet than on the red rays, the former being more refrangible. Now, suppose that the material of which the lens F F is made, be such that at a certain distance from it, at V′ for example, the quantity of dispersion it would produce would be exactly equal to V R. In that case it is evident that the extreme images of O O, the violet image and the red image would be equally affected in contrary directions by the two lenses C C and F F. By C C, the violet image would be brought back, and the red image thrown forward, so as to separate them by the distance V R; but by the lens F F, on the contrary, the violet image is thrown forward, and the red driven back, in exactly the same degree, so that the two images are made to coalesce at R′ V′. As to the intermediate images, although they do not actually coalesce, their dispersion becomes so insignificant as to produce no perceptible chromatic aberration.

The production of this effect depends on the relative dispersive and refractive powers of the material of the two lenses, and on their forms.

This important principle may be further elucidated as follows:

Let L′ L′ (fig. 36, p. 113) be a diverging lens and let it be supposed to receive rays proceeding from a white object which, if not intercepted, would produce a real image of the object at a point O, within the focal distance of the lens L′ L′. In that case the lens L′ L′, according to what has been explained, will produce a series of coloured images of the object at a greater distance from the lens, the red image R′ being nearest, the violet V′ most distant from the lens, the dispersion being R′ V′. Now this dispersion may be increased or diminished by increasing or diminishing the concavity or the diverging power of the lens L′ L′. It is evident, therefore, that such a form may be assigned to the lens L′ L′, as will give the dispersion R′ V′ any desired magnitude.

Let L L and L′ L′ (fig. 37, p. 113) be two lenses made of different materials, the former being a convergent, and the latter a divergent lens. Let O be a white object placed at such a distance from the lens L L, that its violet and red images would be formed at V and R, the distance V R being therefore its dispersion. But instead of allowing the rays transmitted through the lens L L to form this series of images, we will suppose them intercepted by the lens L′ L′, and since the images would fall within its focal length, the effect of L′ L′ will be to throw the images to a greater distance from it; but its effect upon the violet image V, will be so much greater than its effect upon the red image R, that the distance of V from the lens will be more increased than that of R, by a space exactly equal to V R, and consequently the two images will be made to coalesce, and the system will thus be rendered, for all practical purposes, achromatic. We say for all practical purposes, inasmuch as although the conditions here supposed will produce the coincidence of the red and violet images, they will not rigorously produce the coincidence of all those of the intermediate colours. Nevertheless, the general effect will be the production of an image sensibly exempt from chromatic confusion.

A compound lens, which produces such an effect, is called an ACHROMATIC LENS.

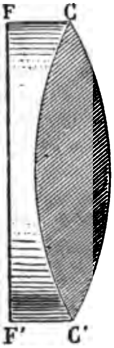
68. The materials which have been found most valuable for achromatic lenses, are flint and crown-glass, which differ considerably in both their refractive and dispersive powers. The refractive and dispersive powers of these sorts of glass, vary according to the proportions of their constituents, but they may always be rendered such as to fulfil the conditions necessary for an achromatic lens.

69. The forms of the lenses shown in fig. 38, are those of a plano-concave of flint, and a double convex of crown glass. It is neither necessary nor expedient that these forms should be adhered to. The crown-glass lens may be double-convex with unequal convexities, or it may be plano-convex or even meniscus. The flint-glass lens may be in like manner double-concave, with unequal concavities, or it may be plano-concave, or concavo-convex. In the same way the curves of the surfaces may be indefinitely varied, the compound lens having still the same focal

length. In the figure, the convex lens is next to the object. This is neither necessary nor usual. They are commonly placed in the contrary position.

The artist has therefore a wide latitude in the construction of achromatic lenses, of which the most eminent opticians have availed themselves with consummate skill and address, so as to efface by the happy combination of curves, not only the spherical aberration, but also the chromatic aberration of the eye-glass, and the spherical distortion of the final image in the compound microscope, as we shall show in our Tract on that instrument.

Fig. 38.



One of the forms of compound lens, which calculation shows to be most free from aberration, is a combination of a double-convex lens of crown-glass, with equal convexities, and a double-concave of flint-glass; the concavity of one face corresponding with the convexity of the crown lens, the radius of the concavity of the other face being 23½ times that of the crown lens. But since such a concavity within the limits of the face of the lens would (fig. 30) be practically undistinguishable from a plane surface, opticians have combined a plano-concave of flint with the double-convex of crown-glass, which gives all the achromatism that can be desired.

An achromatic lens of this kind is shown in section in fig. 38, where C C is the double-convex crown, and F F the plano-convex flint lens.

The discovery of the method of constructing achromatic object-glasses for telescopes and microscopes, constitutes a most important epoch in the history of the progress of physical science. The refraction of light without the production of coloured fringes, which was regarded by Newton, his contemporaries, and his immediate successors, as incompatible with the established properties of light, was first shown to be possible, and, as it appears, even experimentally proved by Mr. Hall, a country gentleman of Worcestershire, about the year 1730. Three years later, he caused an achromatic telescope to be constructed by one of the London makers. Nevertheless, from some cause not known, this discovery proved fruitless, and the matter was neglected and forgotten.

The practical realisation of achromatism in telescope lenses is undoubtedly due to John Dollond, who arrived at their construction through a long course of skilful and systematical experiments undertaken for the express purpose. The possibility of solving the problem had been proved theoretically previous to this by Euler, upon reasoning based upon the structure of the eye.

After Dollond's discovery, the subject was investigated mathematically by Euler, Clairaut, and D'Alembert, but their researches did not lead to any practical improvement, and for a long series of years the lenses produced by the Dollond family enjoyed a monopoly and a European celebrity.

The difficulty in constructing achromatic lenses arises from that of obtaining single pieces of flint glass which are pure and uniform throughout their entire dimensions. The slightest impurity, or want of homogeneity in the composition of the glass, produces a streaked and deformed image.

The method of producing pure flint glass even in pieces of moderate magnitude, long remained a secret with the Dollonds, and it formed a very considerable article of exportation. Of late years, however, the art of producing it has undergone immense improvement in Switzerland, Bavaria, and other parts of the Continent, by the successful experiments of Guinand, Frauenhofer, Cauchoix, Korner, D'Artigues, and others. The object-glasses of Dollond, excellent as they were, never could be obtained of greater diameter than about 5 inches. Frauenhofer, however, has succeeded in producing perfect lenses, having diameters measuring from 12 to 13 inches. An object-glass, manufactured by Cauchoix, which measures more than 12 inches, is mounted in the great parallactic telescope of Sir James South, at Campden Hill.

The exact proportion of the ingredients composing these fine specimens is not certainly known, and the excellence of particular pieces depends on accidental circumstances not known or controlled by the makers themselves. Korner produced some of his best specimens with the following ingredients:—Quartz, previously treated with muriatic acid, 100; litharge, or red lead, 80; and bitartrate of potash, 30.

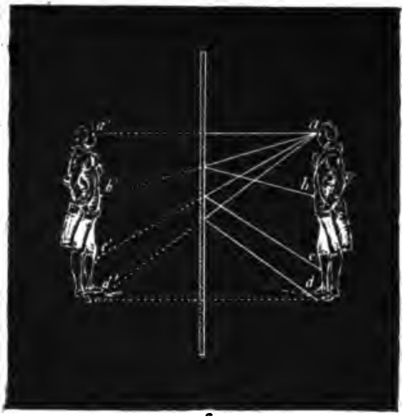


Fig. 1.

COMMON THINGS.

THE LOOKING-GLASS.

1.—Though common and familiar, little understood.—2. Image of an object produced by it vertically erect, but laterally inverted.—3. Image of an object parallel to the looking-glass.—4. Image of an object inclined to the reflector.—5. Series of images formed by two reflectors.—6. Example in rooms furnished with several mirrors.—7. Reflection by a looking-glass takes place at the posterior surface—silvering.—8. Analysis of the effect of a looking-glass upon the light falling on it.—9. Conditions on which the goodness of a looking-glass depends.—10. Effect of mirrors flush with the floor.—11. Best method of cleaning mirrors.—12. Light reflected from the silvered surface.—13. How a double image is produced.—14. Why one image is much more faint than the other.—15. Positions in which the two images are visible.—16. The image usually seen produced by the posterior surface.—17. Effect of light absorbed by the glass.—18. Glasses rendered unfaithful in their tints.—19. A good glass must have its surface parallel.—20. Defects of low-priced glasses.

1. How common and familiar in all countries, and all houses—from the palace to the cottage—is that useful and beautiful article the looking-glass. Its fragments presented to savages are prized above gold, excite their wildest admiration and unbounded astonishment; its uses and its abuses have, in all times, supplied a theme to the moralist, a figure to the orator, a metaphor to the poet, and fanciful allusions without number to the dramatist.

Since a very small proportion of the millions who place themselves daily before the looking-glass, and profit by its silent, obedient, and most perfect ministrations, are in the least degree aware of the admirable optical experiment which they perform, nor of the principle upon which so faithful a reproduction of their person and lineaments depends, it will neither be unprofitable nor uninteresting, to place before our readers a brief exposition of the Theory of the Looking-glass.

2. It has been already shown in our Tract upon "Optical Images," that when an object is placed before a plane reflector, the rays of light which diverge from each point of its surface, after falling upon the reflector, will be thrown back, or reflected as if they had proceeded from a point as far behind the reflector as the point from which they did actually proceed, is before it. It follows from this, that an observer in front of the reflector, receiving in this manner the reflected light, as if it came from a similar object behind the reflector, will have a perception of such an object. Thus, when he stands at a certain distance before the reflector, as in fig. 1, he sees his own image standing face to face with him, just as far behind the reflector as he is before it. The head of the image will correspond in position with his head, and the feet with his feet, that is to say, the image will be erect and not turned upside down, as is the case with some other optical images, as may be seen by reference to our Tract on that subject. But an inversion will be produced when the image is considered laterally; this will be understood when it is considered that the observer and his image are looking in opposite directions since they stand face to face. If the observer, for example, look to the north, his image looks to the south, and in that case the right hand of the observer would be to the east, and his left to the west, while the right hand of his image would on the contrary be to the west, and the left to the east. Thus, the reflection of the right hand of the observer would be the left hand of his image, and the reflection of his left hand would be the right hand of the image.

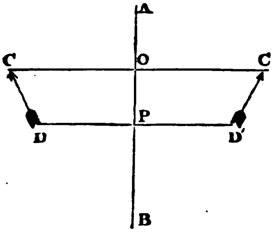
This effect is rendered strikingly manifest by holding before a reflector a printed book. On the image of the book all the letters will be reversed.

3. If an object be parallel to the surface of a looking-glass, its image will also be parallel to it, for since in that case all parts of the object are equally distant from the reflecting surface, all parts of the image must be also equally distant from it.

4. It follows also, from what has been explained, that if an object be not parallel to a reflector, but forms an angle with it, the image will form a like angle with it, and will form double that angle with the direction of the object.

Let A B, fig. 2, be a plane reflector, before which an object C D is placed. From C draw the perpendicular C O, and continue it from O to C′, so that O C′ shall be equal to O C. In like manner, draw the perpendicular D P, and continue it so that P D′ shall be equal to P D. Then the image of C will be at C′, and the image of D at D′, and the image of all the intervening points between C and D will be at points intermediate between C′ and D′, so that C′ D′ shall be inclined to the reflector at the same angle as C D is inclined to it, and the object and the image will be inclined to each other at twice the angle at which either is inclined to the reflector.

Fig. 2.



Hence, if an object in a horizontal position be reflected by a reflector forming an angle of 45° with the horizon, its image will be in a vertical position; and if the object being in a vertical position be reflected by such a mirror, its image will be in a horizontal position.

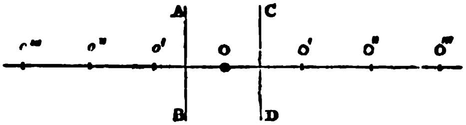
If a reflector be placed at an angle of 45° with a wall, the image of the wall will be at right angles with the wall itself.

If a reflector be horizontal the image of any vertical object seen in it will be inverted. Examples of this are rendered familiar by the effect of the calm surface of water. The country on the bank of a calm river or lake is seen inverted on its surface.

5. If an object be placed between two parallel plane reflectors, a series of images will be produced lying on the straight line drawn through the object perpendicular to the reflector. This effect is seen in rooms where mirrors are placed on opposite and parallel walls, with a lustre or other object suspended between them. An interminable range of lustres is seen in each mirror, which lose themselves in the distance and by reason of their faintness. This increased faintness by multiplied reflection arises from the loss of light caused in each successive reflection, and also from the increased apparent distance of the image.

Let A B and C D, fig. 3, be two parallel reflectors; let O be an object placed midway between them. An image of O will be formed at O′ as far behind C D as O is before it, and another image will be formed at *o′* as far behind A B as O is before it. The image O′ becoming an object to the mirror A B, will form in it another image *o″* as far behind A B as O′ is before it, and in like manner the image *o′* becoming an object to the mirror C D will form an image O″ as far behind C D as *o′* is before it. The images O″ and *o″* will again become objects to the mirrors A B and C D respectively; and two other images will be formed at equal distances beyond these latter. In the same way we shall have, by each

Fig. 3.



pair of images becoming objects to the respective mirrors, an indefinite series of equidistant images.

6. The distance between each successive pair of images will be equal to the distance of the object o from either of the images o′ or *o′*, and consequently to the distance between the mirrors.

These effects may be seen in rooms where two looking-glasses are attached to opposite and parallel walls, with a lamp or chandelier suspended between them. In such cases an indefinite row of lamps will be seen in each glass, each becoming fainter and fainter as the images are more distant.

7. In the preceding explanation of the effects produced by plane mirrors, it has been assumed that the reflections by which the phenomena are produced, take place from the surface of the mirror. In the case, however, of mirrors made of glass in the usual manner, there are two surfaces, the anterior and the posterior, which ought to be, and in good glasses always are, truly parallel. The posterior surface is coated with a metallic composition called an amalgam of tin, which consists of a combination of tin and mercury, produced by diffusing mercury on the well-cleaned surface of the glass, and then laying upon it a sheet of tin foil. The mercury immediately combines with the tin, forming an amalgam which closely adheres to the glass, and forms a perfectly opaque coating upon it.

8. When the ray of light proceeding from any object placed before the glass falls upon its anterior surface, it is resolved into three parts to which severally it is necessary to give especial attention inasmuch as the quality and goodness of the looking-glass altogether depends on them.

The first and principal part enters the surface, and being refracted by the glass passes through it to the posterior surface. What happens to this part we shall presently see.

The second part is reflected from the anterior surface according to the laws of reflection already explained, and produces an image visible to an observer in front of the glass.

The third is reflected from the surface of the glass not according to the laws of reflection explained above, but in the same manner as that in which light is reflected from the surface of ground-glass. It is this part of the reflected light which renders the anterior surface of the glass visible.

9. Since the perfection of the illusion which the looking-glass is intended to produce requires that the spectator, who directs his view to the glass, should see nothing except the optical image of the scene which is before the glass, it is evident that the last mentioned part of the incident light must necessarily have a tendency to destroy the illusion by rendering the surface of the glass itself visible. The less therefore the portion of the light is, which is reflected in this manner, the more perfect will be the glass. When a glass is highly polished, and perfectly free from scratches, the part of the light thus radiated from its surface, though not strictly speaking nothing, is nevertheless so exceedingly small as to produce no sensible effect on the eye. So great is the perfection to which the surface of plate-glass has been brought in this respect, that a plate of looking-glass brought down to the surface of the carpet in a room produces so perfect an illusion, that a person with good sight would take it for an open door and walk through it.

10. Large mirrors thus set in rooms flush with the carpet, and surrounded with framing fashioned like that of open folding-doors, have the apparent effect of converting a single room into a vast suite of rooms, and when the mirrors are of good quality the illusion is so complete, that persons are only prevented from attempting to walk from room to room by meeting their own image in the door-way, which generally excites a sensation of indescribable surprise.*

When, however, glasses have the polish of their surface more or less deteriorated by long use, and above all by constant and improper cleaning, the part of the light radiated in this manner is so much increased that their surfaces become visible, especially when they are viewed obliquely.

11. Where valuable glasses require frequent cleaning great care should be taken as to the manner in which the operation is performed, since otherwise they will soon lose their polish and be very much deteriorated in beauty and diminished in value. The dust which collects upon them should be first removed by means of a duster of feathers,† and they should then be cleaned either with wash-leather or old cambric. Nothing can be more

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* I have made this optical experiment in one of the rooms of my own house, and have often observed the result above described.

† Called in France a *plumeau.* I am informed that this article of household convenience does not exist in England; nevertheless, it is of great and constant utility elsewhere as an instrument of domestic neatness.

injurious than whiting applied in the customary way for this purpose. The leather, however, may be impregnated with putty or crocus powder. When the value of large-sized looking-glasses, and their great durability when properly treated, are considered, such precautions for their due preservation will not be considered superfluously extreme.

12. Let us now return to that part of the light which penetrates the anterior surface, and passing through the glass encounters the posterior or silvered surface. A certain small proportion of this is absorbed by the glass in passing through it, but the chief part arrives at the silvered surface by which it is reflected according to the laws already explained, and returning through the glass, passes through the anterior surface, and issuing from it produces all the phenomena which have been explained in the preceding paragraph.

13. It follows therefore, that since both surfaces of the glass, the anterior and the posterior, reflect the rays proceeding from any object placed before it, independently of each other, two optical pictures of each object will be produced one in front of the other; but since the number of rays reflected by the anterior surface is incomparably smaller than the number reflected from the posterior surface, the picture produced by the latter will be proportionately brighter and more visible than the feebler picture produced by the latter. Nevertheless in certain positions of the observer he latter picture will be perceived.

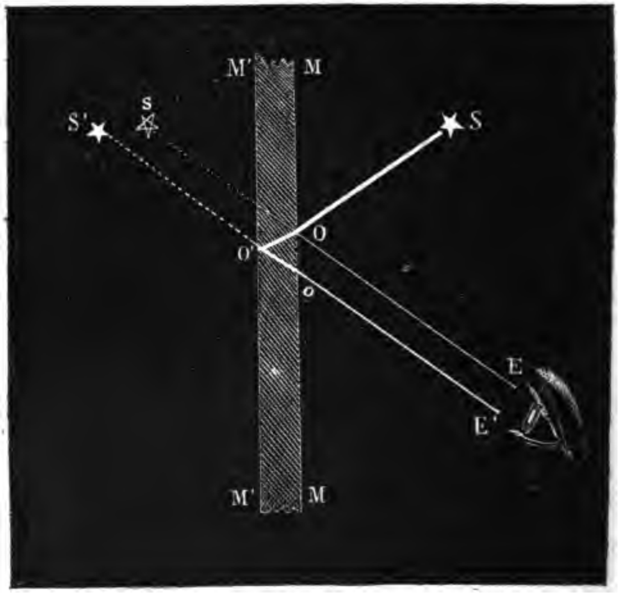
To render this more easily intelligible let M M, fig. 4, be the anterior and M′ M′ the posterior and silvered surface of the glass. Let S be any point of an object placed before it, and let E E′ be the eye of an observer viewing this object in the glass. Let us then see how his vision will be affected.

A ray of light, S O, proceeding from the object, strikes the glass at O. A very small portion of it is reflected to the eye of the observer in the direction O E, so that O E and O S shall make equal angles with the surface M M of the glass. This small portion of light thus reflected in the direction of the line O E causes the observer to see an image, or optical picture of the object, at *s*, in the direction of O E, the image *s* being as far *behind* the surface M M as the object S is *before* it. But since the portion of light proceeding from O to E is so very small, the image *s* will be proportionally feeble.

The chief part of the beam of light entering the glass is refracted in the direction O O′, making a very obtuse angle with its original direction S O, and encountering the silvered surface at O′, it is reflected back through the glass in the direction O′ *o*, so that the rays O O′ and O′ *o* are equally inclined to the surface M′ M′.

On emerging from the anterior surface of the glass, the ray is again refracted, taking the direction O E′, which makes with O O′

Fig. 4.



the same obtuse angle as S O made with O O′. The eye placed at E′, therefore receiving the ray of light in the direction *o* E′, sees the object S as if it were at S′.

14. The light in passing through the glass from O to O′, and from O′ to *o*, loses more or less by the absorption of the glass. A small part also is lost by imperfect reflection, at O′, and again in emerging from the anterior surface, a small portion of the light is reflected back through the glass.

From these causes, the image seen at S′ is a little more faint than the object S, of which it is the reflection. But the image *s*, produced by the reflection of the anterior surface, is incomparably more faint.

15. The line S′ S, which joins the two images being at right angles to the surfaces of the glass, will be viewed more and more obliquely, the less oblique the line of vision E O is to the glass, and

when this line is perpendicular to the glass, the image *s* is directly between the eye and S′, so that the one is projected on the other, and they are seen as a single image. Hence it arises that when a person looks at himself in a glass, he never in any case can see the double image, since in that case the line of vision must be always at right angles to the glass. But when he views an image of another object from a point such as E, where the line of vision is oblique to the surface of the glass, the images are separated more or less, according to the obliquity of the line of vision. The nearer the eye is to the surface of the glass, the more nearly at right angles to S′ *s* will be the line of vision E′ O′ S′, and the more widely will the images appear separated.

16. The image which is actually seen in the looking-glass is then chiefly that which is reflected by the posterior surface of the glass, and not as many are apt to imagine, that reflected by the anterior surface. If any further evidence of this be required, it will be readily found in the fact that an unsilvered plate of glass shows by reflection scarcely any perceptible image, although the reflection from its anterior surface is exactly the same as if it were silvered at the posterior surface. The superior brilliancy of the image reflected by the posterior silvered surface is so decided as to overpower the more feeble image produced by the anterior surface, except in the extreme cases of very great obliquity of the visual rays.

17. All translucent media have the effect of absorbing more or less of the light which is transmitted through them, and to such an extent does this absorption take place, that such media will actually absorb all the light which enters them, if their thickness exceeds a certain limit. It happens also that such a transparent body has a greater tendency to absorb lights of particular tints of colour than others. Thus, while some will absorb a greater proportion of the reddish, others will absorb a greater proportion of the bluish tints.

If the glass of which a mirror is formed have an equal tendency to absorb light of all colours, it will reflect all objects placed before it in their natural colours, but rendered somewhat more faint than the objects themselves. The less light is thus absorbed, the more nearly will the reflection correspond with the object, and the more perfect will be the mirror.

18. If, however, as happens more commonly, the glass have a tendency to absorb particular colours more than others, the object reflected in the glass will appear in false tints, more or less pronounced, according to the degree of the absorption, and the colours of the light absorbed. If the bluish tints be absorbed in excess, the objects reflected will be more of a reddish tint; and if the

reddish tints be absorbed in excess, the objects reflected will have a tendency to greenish or bluish tints.

19. A good looking-glass should have its two surfaces truly parallel and truly plane. If they are not truly parallel, the separation of the images produced by the anterior and posterior surfaces will be augmented, and confusion will be produced. If the surfaces be not truly plane, the relative position of the images, and of different parts of the same image, will not correspond with that of the objects and parts of the same object, and consequently distortion will ensue.

20. A good mirror plate must also be perfectly homogeneous, since otherwise the rays would be differently refracted in passing through it, as well from front to back as from back to front, and consequently distortion would in that case also be produced.

These defects may generally be observed to prevail more or less in the more common and low-priced sorts of looking-glasses, which are often so striated as to reflect images utterly distorted.

THE TIDES.

1. Their correspondence with the lunar phases known at an early period.—2. Erroneous notions prevalent as to their causes.—3. Not caused by the moon's attraction.—4. But by the inequality of its attraction.—5. Calculation of this inequality.—6. Solar tides.—7. Difference between the power of the sun and moon to produce a tide.—8. Spring and neap tides.—9. Why the tides are not directly under the moon.—10. Establishment of the port.—11. Effects of the form of the coasts upon the local tides.—12. Dr. Whewell's analysis of the progress of the tidal wave.—13. Age of the tide.—14. Velocity of the tide.—15. Undulations.—16. Motion of the crest of a wave.—17. Range of the tide.—18. How affected by the weather.

1. The phenomena of the tides of the ocean are too remarkable and too important to the social and commercial interests of mankind, not to have attracted notice at an early period in the progress of knowledge. The intervals between the epochs of high and low water everywhere corresponding with the intervals between the passage of the moon over the meridian above and below the horizon, suggested naturally some physical connexion between these two phenomena, and indicated the probability of the cause of the tides being found in the motion of the moon.

Kepler developed this idea, and demonstrated the close connexion of the phenomena; but it was not until the theory of

GRAVITATION was established by Newton, and its laws fully developed, that all the circumstances of the tides were clearly explained, and shown incontestably to depend on the influence of the sun and moon.

2. There are few subjects in physical science about which there prevail more erroneous notions among those who are but a little informed, than with respect to the tides. A common idea is, that the attraction of the moon draws the waters of the earth toward that side of the globe on which it happens to be placed, and that consequently they are heaped up on that side, so that the oceans and seas acquire there a greater depth than elsewhere; and thus it is attempted to be established that high water will take place under, or nearly under, the moon. But this neither corresponds with the fact, nor, if it did, would it explain it. High water is not produced merely under the moon, but is equally produced upon those parts most removed from the moon. Suppose a meridian of the earth so selected, that if its plane were continued beyond the earth, it would pass through the moon; then we find that, subject to certain modifications, a great tidal wave, or what is called *high water*, will be formed *on both sides* of this meridian; that is to say, on the side next the moon, and on the side remote from the moon. As the moon moves in her monthly course round the earth, these two great tidal waves follow her. They are, of course, separated from each other by half the circumference of the globe. As the globe revolves with its diurnal motion upon its axis, every part of its surface passes successively under these tidal waves; and at all such parts as pass under them, there is the phenomenon of high water. Hence it is that in all places there are two tides daily, having an interval of about twelve hours between them. Now if the common notion of the cause of the tides were well founded, there would be only one tide daily; viz., that which would take place when the moon is at or near the meridian.

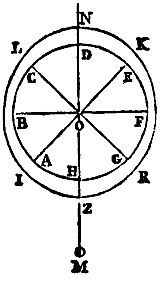
3. That the moon's attraction upon the earth simply considered would not explain the tides, is easily shown. Let us suppose that the whole mass of matter on the earth, including the waters which partially cover it, were attracted *equally* by the moon; they would then be equally drawn towards that body, and no reason would exist why they should be heaped up under the moon; for if they were drawn with the same force as that with which the solid globe of the earth under them is drawn, there would be no reason for supposing that the waters would have a greater tendency to collect towards the moon than the solid bottom of the ocean on which they rest. In short, the whole mass of the earth, solid and fluid, being drawn with the same

force, would equally tend towards the moon; and its parts, whether solid or fluid, would preserve among themselves the same relative position as if they were not attracted at all.

4. When we observe, however, in a mass composed of various particles of matter, that the relative arrangement of these particles is disturbed, some being driven in certain directions more than others, the inference is, that the component parts of such a mass must be placed under the operation of different forces; those which tend more than others in a certain direction being driven with a proportionally greater force. Such is, in fact, the case with the earth, placed under the attraction of the moon. Newton showed that the law of gravitation is such, that its attraction increases as the distance of the attracted object diminishes, and diminishes as the distance of the attracted object increases. The exact proportion of this change of energy of the attractive force, is technically expressed by stating that it is in the inverse proportion of the square of the distance; the meaning of which is, that the attraction which any body like the moon would exercise at any proposed distance, is four times that which it would exercise at twice the distance; nine times that which it would exert at three times the distance; one-fourth of that which it would exercise at half the distance, and one-ninth of that which it would exercise at one-third the distance, and so on. Thus we have an arithmetical rule, by which we can with certainty and precision say how the attraction of the moon will vary with any change of its distance from the attracted object. Let us see how this will be brought to bear upon the explanation of the effect of the moon's attraction upon the earth.

Let A, B, C, D, E, F, G, H, represent the globe of the earth, and, to simplify the explanation, let us first suppose the entire surface of the globe to be covered with water. Let M be the moon, and let H be the nearest, and D the most remote part of the earth. Now it will be very apparent that the various points of the earth's surface are at different distances from the moon: A and G are more remote than H; B and F still more remote; C and E more distant again, and D most remote of all. The attraction which the moon exercises at H is, therefore, greater than that which it exercises at A and G, and still greater than that which it produces at B and F; and the attraction which it exercises at D is least of all. Now this attraction equally affects matter in every state and condition. It affects the particles of fluid as well as solid matter,

Fig. 1.



but there is this difference between these effects; that where it acts upon solid matter, the component parts of which are at different distances from it, and therefore subject to different attractions, it will not disturb their relative arrangement, since such disturbances or disarrangements are prevented by the cohesion which characterises a solid body; but this is not the case with fluids, the particles of which are mobile, and which, when solicited by different forces, will have their relative arrangements disturbed in a corresponding manner.

The attraction which the moon exercises upon the shell of water which is collected immediately under it near the point H, is greater than that which it exercises upon the solid mass of the globe between H and D; consequently there will be a greater tendency of this attraction to draw the fluid which rests upon the surface at H towards the moon, than to draw the solid mass of the earth which is more distant.

As the fluid, by its nature, is free to obey this excess of attraction, it will necessarily heap itself up in a pile or wave over H, forming a more convex protuberance between R and I, as represented in the figure. Thus high water will take place at H, immediately under the moon. The water which thus collects at H, will necessarily flow from the regions B and F, where, therefore, there will be a diminished quantity of water in the same proportion.

But let us now consider what happens to that part of the earth, D, most remote from the moon. Here the waters being more remote from the moon than the solid mass of the earth under them, will be less attracted; and consequently will have a less tendency to gravitate towards the moon. The solid mass of the earth, D H, will, as it were, recede from the waters at N, in virtue of the excess of attraction, leaving these waters behind it, which will thus be heaped up at N, so as to form a convex protuberance between L and K, similar exactly to that which we have already described between R and I. As the difference between the attraction of the moon on the waters at Z and the solid earth under the waters, is nearly the same as the difference between its attraction on the latter and upon the waters at N, it follows that the height of the fluid protuberances at Z and N are nearly equal. In other words, the height of the tides on opposite sides of the earth, the one being under the moon and the other most remote from it, is nearly the same.

Now from this explanation it will be apparent, that the cause of the tides, so far as the action of the moon is concerned, is not, as is vulgarly supposed, due to the mere attraction of the moon; since, if that attraction were equal in all the component parts of the earth, there would assuredly be no tides. We are to look for the cause, then, not in the attraction of the moon, but in the *inequality* of its attraction on different parts of the earth. The greater this inequality is, the greater will be the tides. Hence, as the moon is subject to a slight variation of distance from the earth, it will follow, that when it is at its least distance, or at the point called *perigee*, the tides will be greatest; and when it is at the greatest distance, or at the point called *apogee*, the tides will be least; not because the entire attraction of the moon in the former case is greater than in the latter, but because the diameter of the globe bearing a greater proportion to the lesser distance than the greater, there will be a greater *inequality* of attraction.

It will doubtless occur to those who bestow on these observations a little reflection, that all which we have stated in reference to the effect produced by the attraction of the moon upon the earth, will also be applicable to the attraction of the sun. This is undoubtedly true; but in the case of the sun the effects are modified, in some very important respects, as will readily be seen. The sun is at four hundred times a greater distance than the moon, and the actual amount of its attraction on the earth would, on that account, be one hundred and sixty thousand times less than that of the moon; but the mass of the sun exceeds that of the moon in a much greater ratio than that of one hundred and sixty thousand to one. It therefore possesses a much greater attracting power in virtue of its mass, compared with the moon, than it loses by its increased distance. The consequence is, that it exercises upon the earth an attraction enormously greater than the moon exercises. Now, if the simple amount of its attraction were, as is commonly supposed, the cause of the tides, the sun ought to produce a vastly greater tide than the moon. The reverse is, however, the case, and the cause is easily explained. Let it be remembered, the tides are due solely to the *inequality* of the attraction on different sides of the earth, and the greater that inequality is, the greater will be the tides, and the less that inequality is, the less will be the tides.

5. The rate at which the attraction decreases with the increase of distance being clearly understood, nothing can be more easy of solution than the question of the difference between the influences of the sun and the moon in raising a tide.

The distance, M O, of the moon from the earth's centre is in round numbers sixty semi-diameters of the earth. Its distance, M H, from the nearest part of the earth's surface is therefore fifty-nine semi-diameters of the earth. Now since its attraction upon the entire solid mass of the earth is the same as if it were collected at the centre, O, and since we may regard its attraction on the waters to be the same as if they were collected at H, it will be evident that the moon's attraction on the solid earth will be less than its attraction upon the waters which lie on the nearer side of the earth in the proportion of the square of 60 to the square of 59, that is, as 3600 to 3481, and consequently the *difference* of the two attractions will be to the whole attraction exerted by the moon upon the earth as 119 to 3600, or what is the same, as 1 to 30¼. Thus it appears that the moon's power to raise a tide on the nearer side of the earth is little less than a thirtieth part of its entire attraction on the earth.

By the same method of calculation, the power of the sun to raise a tide may be ascertained. The sun's distance from the centre of the earth is just twenty-four thousand semi-diameters of the earth, and its distance from the waters, on the nearer side of the earth is therefore twenty-three thousand nine hundred and ninety-nine semi-diameters. It follows, therefore, that its attraction on the waters on the nearer side exceeds the attraction on the earth, in the proportion of the square of 24000 to the square of 23999, that is, in the proportion of 576,000000 to 575,952001, and consequently the difference between its attraction on the waters, and its attraction on the solid earth, under the waters, has to its entire attraction the proportion of 47999 to 576,000000, or, what is the same, that of 1 to 12000; so that the sun's power to raise a tide is about the twelve-thousandth part of its whole attraction on the earth.

It appears, therefore, from this reasoning and calculation, that the moon's power to raise a tide is about the thirtieth part of its entire attraction, while the sun's power is the twelve-thousandth part of its attraction. If the entire attraction of the moon were equal to that of the sun, it would therefore follow very obviously that the moon's power to raise a tide would be greater than that of the sun, in the proportion of 12000 to 30, or what is the same, of 400 to 1. But the proportion in favour of the moon's influence is not nearly so great as this, because the entire attraction of the moon is much less than that of the sun. Let us consider in what proportion it is less. It is demonstrated by astronomers, that the mass of the sun is 28,394880 times greater than that of the moon. If the sun, therefore, were as near the earth as the moon is, its attraction would be 28,394880 times greater than that of the moon. But being at a distance 400 times greater than that of the moon, its attraction is diminished in the proportion of the square of 400, or 160000 to 1. Its actual attraction will, therefore, be found, relatively to that of the moon, by merely dividing 28,394880 by 160000, which gives 177½.

6. Since, therefore, the moon's power to raise a tide would be

400 times greater than that of the sun, if their entire attractions on the earth were equal, it will be less than this, in the ratio of 177½ to 1, inasmuch as the entire amount of the moon's attraction is less than that of the sun in that proportion. The moon's power to raise a tide is, therefore, greater than that of the sun in the ratio of 400 to 177½, or of 2¼ to 1. Other calculations make it about 2½ to 1.

7. It appears, therefore, that there is a solar as well as a lunar tide; and as the lunar tidal wave follows the diurnal motion of the moon, the solar tidal wave follows that of the sun. When the sun and moon are, therefore, either on the same or on opposite sides of the earth, which they are at the epochs of new and full moon, the two tidal waves will be superposed; but when their directions are most removed one from the other, which they are when the moon is in the quarters, the two tidal waves are most separated, being also ninety degrees of the earth's surface apart.

In the one case, a tide is produced corresponding to the sum of the effects of the actions of the moon and sun; and, in the other case, to their difference.

8. These circumstances will be better understood by referring to the illustrative diagrams. In fig. 2, S represents the sun, M the moon when new, and M′ when full. The solar and lunar tidal waves in these cases coincide, and are heaped one upon the other, producing what are called SPRING TIDES.

In fig. 3, S represents the sun, and M and M′ the moon in the quarters. In this case, the solar tidal wave is ninety degrees or a quarter of the earth's circumference from the lunar tidal wave, and the waters which form it are necessarily drawn from the side of the earth on which the lunar tide places itself. It is evident, therefore, that, in this case, the solar tide being formed at the expense of the lunar, the latter will be much less high. The tides in this case are called NEAP TIDES.

9. If physical effects followed immediately, without any appreciable interval of time, the operation of their causes, then the tidal wave produced by the moon would be on the meridian of the earth directly under and opposite to that luminary; and the same would be true of the solar tides. But the waters of the globe have, in common with all other matter, the property of inertia, and it takes a certain interval of time to impress upon them a certain change of position. Hence it follows that the tidal wave produced by the moon is not formed immediately under that body, but follows it at a certain distance. In consequence of this, the tide raised by the moon does not take place for two or three hours after the moon passes the meridian; and

as the action of the sun is still more feeble, there is a still greater interval between the transit of the sun and the occurrence of the solar tide.

But besides these circumstances, the tide is affected by other

Fig. 2.

Fig. 3.

causes. It is not the separate effect of either of these bodies, but the combined effect of both, and at every period of the month, the time of actual high water is either accelerated or retarded by the sun. In the first and third quarters of the moon, the solar tide is westward of the lunar one; and, consequently, the actual high water, which is the result of the combination of the two waves, will be to the westward of the place where it would have been if the moon acted alone, and the time of high water will therefore be accelerated. In the second and fourth quarters the general effect of the sun is, for a similar reason, to produce a retardation in the time of high water. This effect, produced by the sun and moon combined, is what is commonly called the *priming* and *lagging* of the tides.

The highest spring tides occur when the moon passes the meridian about an hour after the sun; for then the maximum effect of the two bodies coincides.

The subject of the tides has received much attention from several scientific investigators in Europe. The discussions held at the annual meetings of the British Association for the Advancement of Science, on this subject, have led to the development of much useful information. The labours of Dr. Whewell have been especially valuable on these questions. Sir John Lubbock has also published a valuable treatise upon it. To trace the results of these investigations in all the details which would render them clear and intelligible, would greatly transcend the necessary limits of this notice. We shall, however, briefly advert to a few of the most remarkable points connected with these questions.

10. The apparent time of high water at any port in the afternoon of the day of new or full moon, is what is usually called the *establishment of the port.* Dr. Whewell calls this the vulgar establishment, and he calls the *corrected establishment* the mean of all the intervals of the tides and transits of half a month. This corrected establishment is consequently the luni-tidal interval corresponding to the day on which the moon passes the meridian at noon or midnight.

The two tides immediately following another, or the tides of the day and night, vary, both in height and time of high water, at any particular place with the distance of the sun and moon from the equator. As the vertex of the tide-wave always tends to place itself vertically under the luminary which produces it, it is evident that, of two consecutive tides, that which happens when the moon is nearest the zenith, or nadir, will be greater than the other; and, consequently, when the moon's declination is of the same denomination as the latitude of the place, the tide which corresponds to the upper transit will be greater than the opposite one, and *vice versâ,* the differences being greatest when the sun and moon are in opposition, and in opposite tropics. This is called the diurnal inequality, because its cycle is one day; but it varies greatly at different places, and its laws, which appear to be governed by local circumstances, are very imperfectly known.

11. We have now described the principal phenomena that would take place were the earth a sphere, and covered entirely with a fluid of uniform depth. But the actual phenomena of the tides are infinitely more complicated. From the interruption of the land, and the irregular form and depth of the ocean, combined with many other disturbing circumstances, among which are the inertia of the waters, the friction on the bottom and sides, the narrowness and length of the channels, the action of the wind, currents, difference of atmospheric pressure, &c. &c., great variation takes place in the mean times and heights of high water at places differently situated; and the inequalities above alluded to, as depending on the parallax of the moon, her position with respect to the sun, and the declination of the two bodies, are, in many cases, altogether obliterated by the effects of the disturbing influences, or can only be detected by the calculation and comparison of long series of observations.

12. According to Dr. Whewell, the general progress of the great tide-wave may be thus described:—It is only in the Southern ocean, between the latitudes of 30° and 70°, that a zone of water exists of sufficient extent to allow of the tide-wave being formed. Suppose, then, a line of contemporary tides, or *cotidal line*, to be formed in the Indian ocean, as the theory supposes, that is to say, in the direction of the meridian, and at a certain distance to the eastward of the meridian in which the moon is. As this tide-wave passes the Cape of Good Hope, it sends off a derivative undulation, which advances northward up the Atlantic ocean, preserving always a certain proportion of its original magnitude and velocity. In travelling along this ocean the wave assumes a curved form, the convex part keeping near the middle of the ocean, and ahead of the branches, which, owing to the shallower waters, lag behind on the American and African coasts, so that the cotidal lines have always a tendency to make very oblique angles with the shore, and, in fact, run parallel to it for great distances. The main tide, Dr. Whewell conceives, after reaching the Orkneys, will move forward in the sea bounded by the shores of Norway and Siberia on one side, and those of Greenland and America on the other, will pass the pole of the earth, and finally end its course on the shores in the neighbourhood of Behring's Straits. It may even propagate its influence through the straits, and modify the tides of the North Pacific. But a branch tide is sent off from this main tide into the German ocean; and this, entering between the Orkneys and the coast of

Norway, brings the tide to the east coast of England and to the coasts of Holland, Denmark, and Germany. Continuing its course, part of it passes through the strait of Dover and meets in the English channel the tide from the Atlantic, which arrives on the coast of Europe twelve hours later; but in passing along the English coast, another part of it is reflected from the projecting land of Norfolk upon the north coast of Germany, and again meets the tide-wave on the shores of Denmark. Owing to this interference of different tide-waves, the tides are almost entirely obliterated on the coast of Jutland, where their place is supplied by continual high water.

In the Pacific Ocean the tides are very small; but there are not sufficient observations to determine the forms and progress of the cotidal lines. Off Cape Horn, and round the whole shore of Terra-del-Fuego, from the western extremity of Magellan's Strait to Staten Island, it is very remarkable that the tidal wave, instead of following the moon in its diurnal course, travels to the *eastward.* This, however, is a partial phenomenon; and a little farther to the north of the last-named places, the tides set to the north and west. In the Mediterranean and Baltic seas, the tides are inconsiderable, but exhibit irregularities for which it is difficult to account. The Indian Ocean appears to have high water on all sides at once, though not in the central parts at the same time.

13. Since the tides on our coast are derived from the oscillations produced under the direct agency of the sun and moon in the Southern Ocean, and require a certain interval of time for their transfer, it follows that, in general, the tide is not due to the moon's transit immediately preceding, but is regulated by the position which the sun and moon had when they determined the primary tide. The time elapsed between the original formation of the tide and its appearance at any place is called the *age* of the tide, and sometimes, after Bernoulli, the *retard.* On the shores of Spain and North America, the tide is a day and a half old; in the port of London, it appears to be two days and a half old when it arrives.

14. In the open ocean the crest of tide travels with enormous velocity. If the whole surface were uniformly covered with water, the summit of the tide-wave, being mainly governed by the moon, would everywhere follow the moon's transit at the same interval of time, and consequently travel round the earth in a little more than twenty-four hours. But the circumference of the earth at the equator being about 25000 miles, the velocity of propagation would therefore be about 1000 miles per hour. The actual velocity is, perhaps, nowhere equal to this, and is very

different at different places. In latitude 60° south, where there is no interruption from land (except the narrow promontory of Patagonia), the tide-wave will complete a revolution in a lunar day, and travel at the rate of five hundred miles an hour. On examining Dr. Whewell's map of cotidal lines, it will be seen that the great tide-wave from the Southern Ocean travels from the Cape of Good Hope to the Azores in about twelve hours, and from the Azores to the southernmost part of Ireland in about three hours more. In the Atlantic, the hourly velocity in some cases appears to be 10° of latitude, or near 700 miles, which is almost equal to the velocity of sound through the air. From the south point of Ireland to the north point of Scotland, the time is eight hours, and the velocity about 160 miles an hour along the shore. On the eastern coast of Britain, and in shallower water, the velocity is less. From Buchanness to Sunderland it is about sixty miles an hour; from Scarborough to Cromer, thirty-five miles; from the North Foreland to London, thirty miles; from London to Richmond, thirteen miles an hour in that part of the river. (Whewell, *Phil. Trans.* 1833 and 1836.) When we speak of the velocity of the tidal wave, it must not be imagined that the mass of water of which the wave is composed has this velocity. If such were the case, its momentum would be destructive indeed. The motion of the tidal wave is only a particular instance of undulatory motion, which is so often misunderstood, and so frequently imputed to the fluid on which the wave is formed, that it may be worth while here to explain it in general.

15. When we see the waves, produced on the surface of the deep, apparently moving in a certain direction, we are very naturally impressed, in the first instance, with the notion that the sea itself is moving in that direction. We imagine that the same wave, as it advances, is composed of the same water, and that the whole surface of the liquid is in a state of progressive motion. The least reflection, however, on the consequences of such a supposition, will soon convince us that it is unfounded. The ship which floats upon the sea, is not carried forward with the waves. They pass in succession under her, now lifting her on their summits, and then letting her sink in the intermediate abyss. Observe a sea-fowl floating on the water, and the same effect will be witnessed. If the water itself partook of the motion of the waves, the ship and the fowl would each be carried forward as if by a current, and would have the same progressive motion as the liquid. Once on the crest of a wave, there they would constantly remain, and their motion would be as smooth as if they were propelled upon the calm surface of a lake; or if once in the hollow

between wave and wave, there likewise they would continually remain, the one wave always keeping before, and the other behind them.

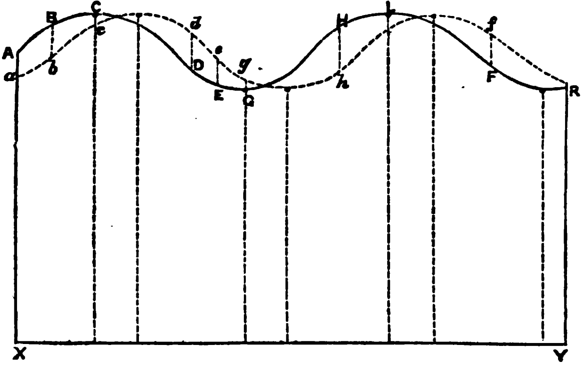
The experiment may be tried upon a tub of water. Let a pebble drop into the centre of it. Rings of waves will immediately be formed round the place where it falls, and they will appear to move outwards from the place of the fall towards the edge of the tub. If a cork be placed anywhere upon the water, it will not be carried by these waves towards the edge of the tub, but will float in the same place, the waves passing successively under it, and the cork rising and sinking as the crest and hollow pass it.

If we observe the waves of the sea breaking on a level strand, we shall soon be convinced that their apparent progressive motion does not affect the water, for if it did, the sea would soon flow in upon the shores, and inundate the adjacent country. So far, however, from the water's partaking of the apparent motion of the waves in approaching the shore, this motion of the waves continues the same even when the water is retiring. If we observe a flat strand when the tide is ebbing, we shall still find the waves moving towards the shore.

16. That this apparent motion of water in a state of undulation is a mere optical illusion we cannot therefore doubt. But we are naturally curious to learn what is the cause of this illusion. That a progressive motion takes place in *something*, we have proof from the evidence of our eyes. That no progressive motion takes place in the liquid we have also proof, from the evidence of our eyes, and from other still more unquestionable testimony. To what then does this progressive motion belong? we answer, to the *form* of the wave, and not to the liquid that composes it.

To make this apparent, let A B C D E, &c. (fig. 4), represent the surface of the sea, C and L being the crests of two successive waves, and G the hollow between them, and let X Y represent the bottom of the sea. After a given interval, ten seconds for example, let the position of the waves be *a b c d e*, &c., the motion being directed from A towards E. Now this motion of the waves is produced in the following manner:—The water which was at A sinks, during the interval of ten seconds, to *a*, the water which was at B sinks to *b*, that which was at C to *c*, that which was at D rises to *d*, that which was at E rises to *e*, that which was at F to *f*, and so on. Thus, in the interval, all parts of the water on one side of a certain point sink, and all those at the other side rise, the extent to which they rise and sink being such, that the surface assumes the new position *a b c d e*, &c. That it is actually the case may be demonstrated by placing on the surface a series of floating bodies, each of which will be observed to rise or sink with the water in the manner here described.

Fig. 4.



It appears, therefore, that the advance of the wave from A C E to *c d h* is in fact produced not by any advance of the water, but by its different points rising and sinking alternately in the vertical direction. It will thus be understood how the *form* of a wave may actually have a progressive motion, while the water that composes it continues always to hold the same position over the bottom. The real motion of the particles of the liquid by which the waves are produced is an alternate vertical motion upwards and downwards through a height equal to the difference between the level of the crest and the hollow of each wave, or what is the same, through twice the height of the crest of the wave above that level at which the water would settle if it were absolutely quiescent and free from all undulation.

If a cloth were laid loosely over a number of parallel rollers placed at equal distances asunder, so that it would fall between roller and roller, it would represent the form of a series of waves. If a progressive motion were given to the rollers, the cloth being kept stationary, the progressive motion of the waves would be produced;—the cloth would seem to advance.

It is the same cause which makes a revolving cork-screw, held in a fixed position, seem to be advancing in that direction in which it would actually advance if the screw were passing through a cork. The point which is nearest to the eye, and which corresponds to the crest of the wave in the former example, continually occupies a different point of the worm, and continually advances towards its extremity.

This property has been prettily applied and illustrated in clocks for the chimney-piece or console. A round rod of glass, twisted so that a ridge in the form of a screw is produced upon its surface, is inserted in the mouth of some figure, such as a lion or a dolphin, which being supposed to discharge water, forms a fountain. The extremity of the glass rod concealed within the mouth of the figure, is fixed on the axis of a wheel, to which a continual motion of rotation is imparted by the works of the clock, and the other end is concealed in the vessel designed to represent the basin, or reservoir, of the fountain. The constant rotation of the twisted glass rod produces the appearance of a progressive motion from the mouth of the figure to the reservoir, as already explained in the example of the cork-screw, and the rod of glass appears like a stream of water continually issuing from the fountain, and falling into the reservoir.

To return to the phenomena of the tides, it is necessary to observe that there is, nevertheless, a real progressive motion of the water directed up the course of tidal rivers, and upon the flat strands of bays and inlets. This, however, is not the progressive motion of the tide-wave, but that of the water falling from the height to which it has been raised, as it might flow down the side of a declivity.

17. The difference of level between high and low water is affected by various causes, but chiefly by the configuration of the land, and is very different at different places. In deep inbends of the shore, open in the direction of the tide-wave and gradually contracting like a funnel, the convergence of water causes a very great increase of the range. Hence the very high tides in the Bristol Channel, the bay of St. Malo, and the bay of Fundy, where the tide is said to rise sometimes to the height of one hundred feet. Promontories, under certain circumstances, exert an opposite influence, and diminish the magnitude of the tide. The observed ranges are also very anomalous. At certain places on the south-east coast of Ireland, the range is not more than three feet, while at a little distance on each side it becomes twelve or thirteen feet; and it is remarkable that these low tides occur directly opposite the Bristol Channel, where (at Chepstow) the difference between high and low water amounts to sixty feet. In the middle of the Pacific it amounts to only two or three feet. At the London Docks, the average range is about 22 feet; at

Liverpool, 15·5 feet; at Portsmouth, 12·5 feet; at Plymouth, also 12·5 feet; at Bristol, 33 feet.

18. Besides the numerous causes of irregularity depending on the local circumstances, the tides are also affected by the state of the atmosphere. At Brest, the height of high water varies inversely as the height of the barometer, and rises more than eight inches for a fall of about half an inch of the barometer. At Liverpool, a fall of one-tenth of an inch in the barometer corresponds to a rise in the river Mersey of about an inch; and at the London Docks, a fall of one-tenth of an inch corresponds to a rise in the Thames of about seven-tenths of an inch. With a low barometer, therefore, the tide may be expected to be high, and *vice versâ*. The tide is also liable to be disturbed by winds. Sir John Lubbock states, that in the violent hurricane of January 8th, 1839, there was no tide at Gainsborough, which is twenty-five miles up the Trent—a circumstance unknown before. At Saltmarsh, only five miles up the Ouse from the Humber, the tide went on ebbing, and never flowed until the river was dry in some places; while at Ostend, towards which the wind was blowing, contrary effects were observed. During strong north-westerly gales the tide marks high water earlier in the Thames than otherwise, and does not give so much water, while the ebb tide runs out late, and marks lower; but upon the gales abating and weather moderating, the tides put in and rise much higher, while they also run longer before high water is marked, and with more velocity of current: nor do they run out so long or so low.

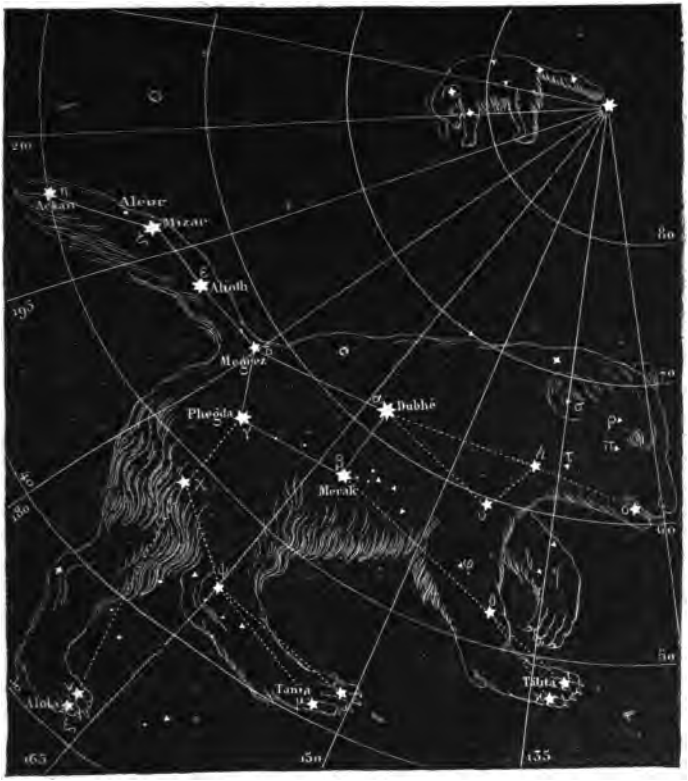


Fig. 2.—CONSTELLATIONS OF THE GREATER AND LESSER BEAR, AND THE POLE STAR.

HOW TO OBSERVE THE HEAVENS.

CHAPTER I.

1. Spectacle presented by the firmament.—2. Useful observations can be made without astronomical instruments.—3. Apparent motion of the firmament.—4. The meridian.—5. View of the circumpolar region. —6. Permanency of the form of the stellar groups.—7. The celestial sphere.—8. The celestial poles.—9. Orders of magnitude of the stars. —10. Number of stars of each order.—11. Constellations.—12. Ursa major.—13. Antiquity of the name.—14. Sometimes called Waggon, Wain, or Chariot.—15. Number of stars in it.—16. Proper names of

stars.—17. Use of the imaginary figure to express the position of the stars.—18. Ursa minor: the pole star.—19. How it makes a nocturnal clock.—20. Arctic circle: origin of the name.—21. Cassiopeia's chair.—22. Pegasus and Andromeda.—23. Perseus.—24. Auriga.—25. General view of the region of these constellations: Capella, Vega, Adrided, and Altair.—26. Orion.

1. To all persons in whose minds a taste for the study of nature has been awakened, there is no spectacle which excites an interest so intense as that which is offered by the firmament on a clear night; and to such there is no occupation more pleasing than from season to season to observe on clear nights the changes which take place in that glorious scene. But to render such contemplation still more agreeable, and to enable the intelligent spectator to turn his observations to profitable account, it is necessary that he should render himself familiar with the objects which are there presented in such countless numbers and endless variety.

2. It is a great error to suppose that all useful astronomical observations must necessarily be confined to observatories, and that no one can taste the pleasures offered by practical astronomy who is not supplied with telescopes and other optical and astronomical apparatus. Our Maker has given us, in the eye, an instrument of exquisite structure, and has supplied us with an understanding, by which that organ may be directed to the most sublime speculations. But even when it is useful that the natural limits of our organs of vision may be extended, and their aim directed with greater precision by artificial and scientific aid, much may be accomplished by the most simple and economical means. A common opera-glass will often give us a distinct view of numerous objects which would otherwise escape the naked eye. The most ordinary telescope will be still more useful. And those who occupy themselves habitually with the celestial scenery, so as to be familiarised with its general features, character, and apparent motions, will not be slow to contrive various simple expedients by which the relative position of objects can be ascertained and measured and the succession of their appearances and disappearances anticipated.

We shall therefore, on the present occasion, endeavour to give such plain and simple rules as may enable every one, by the mere use of his eyes, and still more by the occasional use of such optical aids as are almost universally accessible, to occupy himself advantageously with the contemplation of the heavens.

3. Let us then suppose a person totally ignorant of astronomy to stand with his face directed to the south, and to view the heavens on a clear starlight night. No long time will elapse before he will be rendered conscious that the splendid panorama

presented to him is not stationary. In the course of an hour, he will observe that various objects which were visible above the horizon on his right have disappeared; and that, on the contrary, a corresponding number of objects, which were not visible above the horizon on his left, have come into view. By further attention he will perceive that the objects which were at the mid-heavens, in the direction due south, are now no longer so, but have descended towards the right, that is, towards the west, while objects which were to the left of the mid-heavens will have risen to that region.

4. To assist our explanation, let us imagine the entire firmament divided by a line or great circle, rising from the point of the horizon towards which the observer is supposed to look, and being carried vertically upwards to pass over his head, and to descend behind him to the northern point of the horizon. This great line of division, which is called the celestial meridian, divides the whole visible firmament into two equal parts; one lying to the west, or to the right, and the other to the east, or to the left, of the observer.

By continuing his attentive observation of what goes on before him, he will soon perceive that all the objects visible upon the firmament are in motion. That they rise on the east side; that they ascend to the meridian; and then, descending to the west, pass below the horizon and disappear.

5. Let us now suppose our observer to face round and direct his view to the north. A different spectacle will be presented to him. Supposing him to be placed in these climates, he will soon ascertain that the chief part of the objects which are visible in the firmament do not appear and disappear; that is, they do not rise and set. If, for example, any such object be observed upon the celestial meridian over his head so soon after sunset as the stars become visible, he will observe it from hour to hour to descend on his left, that is, towards the west, and to depart more and more from the meridian. So far, however, this is what equally took place when he looked to the south, and had the west upon his right. But after the lapse of a certain time he will find different appearances to be manifested. At the end of about three hours from the time the object referred to began to depart from the meridian, it will be found to have attained a certain limit of distance from the meridian, which will not be exceeded. After this it will begin, on the contrary, again to approach the meridian; but, in doing so, will also approach the horizon, as though it were ultimately destined to set. Such, however, will not be the case; for, at the end of twelve hours, if the return of daylight be sufficiently retarded to enable our observer still to see

the object, it will have returned to the meridian, without having gone below the horizon or disappeared.

In thus passing from an elevated point of the meridian to another point much lower, the object in question will appear to move over a semicircle of the heavens, of which the part of the meridian between the point from which it departed and the point at which it arrives is the diameter.

If the same object could be seen during the succeeding twelve hours, it would be observed to move over the corresponding semicircle to the east of the meridian, that is, to the right of the observer; and, at the end of this second interval of twelve hours, the object would return to that more elevated point of the meridian from which it started.

Such an object, therefore, never rises or sets; and if the presence of the sun did not render it invisible during the day, it might be seen to revolve continually in a circle of the heavens divided into two equal semicircles, east and west, by the meridian, completing its revolution in such circle, and therefore returning to the same point of the meridian, after an interval of about twenty-four hours.

What has been here stated respecting a single object, is true, with certain qualifications, of an immense number of objects visible to an observer looking to the north, as here supposed. All such objects like that described appear to revolve in circles, but not all in the same circle. Some will be found to revolve in greater, and some in lesser, circles; but all such circles are characterised by two most remarkable circumstances, the first of which is, that they all have the same centre, which is a certain point on the celestial meridian; and the second is, that all the objects which move in them, complete their revolution in precisely the same time.

Such being then the general character of the changes which the scene presented by the heavens to the observer undergoes, let us consider some other important circumstances attending it.

6. After attentively contemplating this spectacle for several nights, the observer will not fail to be struck with the fact, that the relative position and configuration of the objects upon it, remains always unchanged. This remarkable circumstance is rendered the more easily observable by the fact that the objects themselves differ greatly in apparent splendour, some being exceedingly bright and conspicuous, while others are barely distinguishable. The observer soon becomes familiar with the relative arrangement and configuration of the brighter and more conspicuous ones; and, grouping them in his imagination, retains their forms so as immediately to recognise them upon their successive reappearances.

7. This circumstance of the unaltered configuration and relative positions of this multitude of objects scattered over the firmament, suggests irresistibly the idea, that the motion of revolution described above, in which they all participate, is not a motion proper to each separate and independent object, but one which belongs to the firmament itself, upon which they appear as if they were fixed. In short, the firmament presents the aspect of a hollow sphere of vast dimensions, in the centre of which the observer is placed, and upon the surface of which the countless multitudes of objects which he beholds are fixed. This stupendous sphere appears to have a motion of revolution on a certain diameter as an axis, making a complete revolution once in twenty-four hours. The diameter round which it revolves, or appears to revolve, is directed to a certain point of the northern quadrant of the meridian, the altitude of which above the horizon of the observer, will be always found to be exactly equal to the latitude of his station. This motion of revolution of the firmament, carrying with it the numerous objects seen upon it, will perfectly explain all the appearances above described, and many others. Thus, it is evident that all objects on the celestial sphere must be moved in circles parallel one to another round its axis; and that these circles become gradually less as the object is nearer to the pole. When the observer looks to the south, the circles described by the objects are partly above and partly below the horizon; and, consequently, all such objects alternately rise and set. But when he looks to the north, the chief part of the objects which he beholds being nearer to the extremity of the axis round which the sphere is carried, describe circles smaller and smaller, which, being entirely above the horizon, the objects in them neither rise nor set.

8. From what has been stated, it will be obvious, that an object placed precisely at that point of the meridian at which the axis round which the sphere turns terminates, would be immoveable; and would evidently be the only immoveable object in the visible firmament. It does so happen, that there actually is no star precisely at that point; but there is a rather conspicuous one so near to it, that although it moves round it in a small circle, the diameter of which is about six times that of the full moon, such motion can only be ascertained by astronomical instruments; and therefore, for all the purposes of common observation, the star in question may be regarded as stationary, and as indicating the position of the northern extremity of the axis on which the celestial sphere appears to revolve.

This point of the sphere is called its *pole;* and as there is a corresponding point at the other extremity of the axis, which is below the horizon, and therefore invisible, it also receives the name pole, and the two points are distinguished,—the visible one as the *North Celestial Pole*, and the invisible one as the *South Celestial Pole.*

The motion of the celestial sphere here described is apparent, not real, being merely an optical illusion produced by the diurnal rotation of the earth upon its axis. But this being a point not immediately connected with our present purpose, it will be sufficient here merely to indicate it. The readers who desire to see the explanation of the apparent diurnal motion of the heavens, will find it in the "Museum," vol. iii. pp. 55, 56.

For all the purposes of the observation of the heavens which for the present occupy our exclusive attention, the celestial sphere is to be considered as revolving on its axis once in about twenty-four hours, carrying with it all the objects seen upon it.

9. The objects scattered over this sphere in such vast numbers, differing one from another greatly in their apparent splendour, and being characterised by very various and often remarkable configurations, astronomers have invented a nomenclature to designate them, founded partly on their relative splendour, and partly on their configurations.

A catalogue of the stars being made, in which each star would hold a place determined by its relative splendour, the more splendid having the higher places; if it were required to resolve such a list into classes, according to their decreasing degrees of brightness, it would be impossible to fix upon any points where each succeeding class would end and the next begin; the gradations of brightness, when star is compared with star, being altogether imperceptible. Nevertheless, a distribution according to degrees of relative splendour being by the common consent of astronomers of all ages deemed expedient, such a conventional classification has been adopted, arbitrary as the limits of the succeeding classes must necessarily have been. In this a certain number of the most splendid stars visible in the firmament have received the denomination of *stars of the first magnitude;* others, of inferior brightness, are called stars of the *second* magnitude, and so on, the smallest stars visible to the naked eye being classed as stars of the *sixth* magnitude.

10. The number of stars of each succeeding magnitude increases rapidly as their splendour diminishes. Thus, while there are no more than 18 or 20 of the first magnitude, there are 50 or 60 of the second, about 200 of the third, and so on; the total number visible to the naked eye, up to the sixth magnitude inclusive, being from 5000 to 6000. We shall see on another occasion that this number, great as it is, is no more than an insignificant fraction

of the total number of stars, the existence of which the telescope discloses to us. But we shall, for the present, limit our observations to the stars which are visible to the naked eye.

It has been stated that the celestial objects generally maintain with relation to each other a certain invariable position, and have no other motion than that imparted to them in common by the sphere to which they are imagined to be attached. To this, however, there is a limited number of exceptions. There is a small number of objects, among which the sun and moon are the most conspicuous, which, while they participate in the diurnal motion of the celestial sphere, are observed continually to shift their position on it, just as if a number of insects were creeping slowly upon the surface of a top while the top is spinning, carrying the insects round with it. These objects, which, exclusive of the sun and moon, are called *Planets*, have occupied our attention on a former, and will again on a future, occasion; for the present, however, we must be understood to notice only those which maintain invariable relative positions, and which have therefore been denominated *fixed stars*.

11. The nomenclature of the stars, so far as it is founded upon their apparent relative positions, consists in the resolution of all the stars of the firmament into a certain limited number of groups, called *Constellations*. These groups have been from ancient times invested with the imaginary forms of men, animals, and various other objects, natural and artificial, and have been named in accordance with these. Thus, the celestial spaces are partitioned out arbitrarily and conventionally into distinct compartments, in a manner somewhat resembling the divisions of the land on the surface of the globe into empires and kingdoms. Each such compartment of the heavens contains a certain number of stars, great and small, the total assemblage of which constitutes the constellation, and is characterised by the proper name conferred upon it.

Since it is of the first necessity that the astronomical student and amateur should be so familiar with this stellar nomenclature as to be able readily to distinguish and recognise not only each principal constellation, but also each principal star in such constellation, we propose here to give such explanations as will present the greatest practicable facilities in the attainment of this object.

The stars composing each constellation are designated by the letters of the Greek alphabet, the first letters being given to the more splendid stars. When the number of stars in a constellation exceeds the number of letters in the Greek alphabet, the letters of the Roman alphabet are used; and when these are exhausted, the remaining stars, if any, are expressed by the numbers prefixed to them in the catalogue of Flamstead, generally known as the British Catalogue.

It has been customary among English astronomers to designate the constellations by their Latin names; and the astronomical amateur, besides rendering himself familiar with these, will find it convenient, when he is not a Greek scholar, to make himself acquainted with the characters and names of the letters of the Greek alphabet, which are as follows:—

α	Alpha.	ν	Nu.
β	Beta.	ξ	Xi.
γ	Gamma.	ο	Omicron.
δ	Delta.	π	Pi.
ε	Epsilon.	ρ	Rho.
ζ	Zeta.	ς	Sigma.
η	Eta.	τ	Tau.
θ	Theta.	υ	Upsilon.
ι	Iota.	φ	Phi.
κ	Kappa.	χ	Chi.
λ	Lambda.	ψ	Psi.
μ	Mu.	ω	Omega.

12. To obtain an acquaintance with the several constellations and the stars composing them, so as to be able readily to recognise them on viewing the heavens on a clear night, the student should in the first instance study the form and disposition of one of the most conspicuous of the constellations, and the most suitable for this purpose is that which is called *Ursa major*, or the *great Bear*. This constellation is so near the north celestial pole, that in our latitudes it never sets, and is consequently visible at all seasons of the year. It consists of a considerable number of stars, but seven of these, shown in fig. 1, are much more conspicuous than the others, and are consequently the only stars popularly identified

Fig. 1.

with the constellation. They are arranged in such a form, that lines connecting them one with another successively would have the shape of a note of interrogation, or of a reaping-hook.

13. In consequence of the proximity of this constellation to the pole, it never sets in any latitude above that of 40°, and is consequently visible at night in all seasons of the year in the greater part of the northern hemisphere. This circumstance, combined with the splendour of the stars composing it and their remarkable configuration, rendered it an object of universal observation and attention in the earliest ages; and it may therefore be regarded as one of the most ancient of the constellations. It is frequently referred to in the Hebrew Scriptures, and has at various times and in various countries received different denominations. It is referred to, for example, in the book of Job; but the name by which it is designated has been mistranslated in the English version by *Arcturus*, the name of a star in a different constellation. Bochart says that the Hebrew word in Job is derived from an Arabic one which signifies *bier;* others maintain that it signifies a *waggon*, which would be quite consistent with the names given to the constellation by various people, ancient and modern, Greeks, Romans, Italians, Germans, and English, by whom severally it has been named Ἅμαξα (*Amaxa*), waggon or wain; *plaustrum*, cart; *triones*, a waggon and oxen; *feretrum*, bier; *Cataletto*, bier; *Wagen*, waggon; *David's Car*, the *Plough*, and *Charles' Wain*.

14. When the constellation was thus named, the four stars marked α β γ and δ were considered to represent the wheels, and the other three stars the shafts, poles, horses or oxen. When the name *bier* was applied to it, the four stars forming the quadrangle were considered to represent the sarcophagus, and the three remaining stars were considered to represent three mourners, or, according to some, three children of the deceased. Admiral Smyth quotes Kircher as affirming that the four stars of the quadrangle represent the bier of Lazarus, and that the three remaining stars are Mary, Martha, and Magdalen. He also maintains that the popular name of Charles' Wain is a corruption of the Gothic *Karl Wagen*, the churl or peasant's cart.

It is a fact worthy of remark, recorded by historians, that the Iroquois, a tribe of North American Indians were found at the moment of the discovery of America to be familiar with the constellation of the *great Bear*, which in their language was called *Oquoari*, the word which signifies *bear*.

15. Although the only stars of this constellation familiar to the popular eye are the seven principal ones indicated in fig. 1, the group which has received the name of *Ursa major* included from

the earliest times many others of inferior splendour, and this number has been gradually augmented as the range and accuracy of observations have been increased by the improvement of telescopes. From the era of Ptolemy, A.D. 150, to that of Copernicus, A.D. 1500, this constellation contained 35 stars. In the time of Kepler, A.D. 1600, the number was augmented to 56. In Flamstead's Catalogue, A.D. 1700, the number was further augmented to 87, and, in fine, at the beginning of the present century, it was increased to 338.

The constellation, including the stars composing it so far as they are visible without a telescope, is shown in fig. 2, p. 145, where the position and form of the imaginary figure of the bear relatively to the stars are indicated. It will be seen that the four stars α β γ and δ are upon the side, the three others marking the tail.

16. It will be observed in fig. 2 that the principal stars of the constellation, besides being indicated by the Greek letters, are also designated by certain proper names, mostly of Arabic or Oriental origin; and it may here be stated in general that besides the method of designating stars by naming the constellation to which they belong, and the letter which distinguishes them in such constellation, most of the conspicuous stars have received proper names which probably were conferred upon them before the system of constellations was established; and many of these stars are now much more frequently designated by these proper names than by that which connects them with the constellation. Thus, for example, the most splendid star in the constellation of *Canis major* or the *greater Dog*, instead of being called α *Canis majoris*, which would be its name in the nomenclature of the constellations, is almost invariably called *Sirius*. In the same manner, the principal star of the constellation *Leo*, is always called *Regulus* and never α *Leonis*.

These observations, however, are not applicable in the same manner to the seven principal stars of Ursa major, which are more generally designated by the Greek letters which connect them with the constellation.

17. The position of the stars composing a constellation is also frequently indicated by naming the part of the imaginary figure designating the constellation at which the star is found. Thus, for example, the position of η Ursæ majoris, is indicated by stating that it is at the tip of the tail. In like manner, the position of a certain star in the constellation *Taurus*, is indicated by stating that it is in the "bull's eye." This form of expression, which is in very frequent use with astronomers, seems to render it unadvisable to efface altogether from maps of the stars the figures designating the constellations, as is sometimes done.

Although the proper names of the principal stars of Ursa major are not now in general use, they ought not on that account to be altogether overlooked or neglected, since they are often the means of identifying these objects with those indicated in ancient historical records.

Close to the star Mizar, in the tail of the Great Bear, is a small star called *Alcor*, which Humboldt says the Arabs called "saidak," which signifies *trial* or *test*, since they used it as a test of the sharpness of the sight of the observer.

18. If a straight line be imagined to be drawn from the star β to α, and continued beyond α to a distance equal to five times the distance between α and β, or, what is nearly the same, to the whole distance between α and η, it will arrive at the principal star of a smaller constellation called *Ursa minor* or the *lesser Bear*. This is the star already mentioned as being within a degree and a half of the pole, and which, being generally adopted as the easiest practical means of marking that important point, is called the *Pole star*. The other stars of the constellation of Ursa minor have nearly the same configuration as those of Ursa major; but the position of the figure is reversed, the tail, at the tip of which the pole star is placed, corresponding with the head of Ursa major.

The important service thus performed by the stars α and β Ursæ majoris, in indicating by their direction the position of the pole star, has given them the name of the *Pointers;* they are also sometimes called the *Guards*.

This method of ascertaining the position of the principal star and the constellation generally of Ursa minor, by means of the more conspicuous and better known constellation of Ursa major, has been generalised with the greatest benefit to astronomical students and amateurs by extending the method of pointers, so as to trace one constellation from another throughout the entire firmament, as will presently appear.

19. The constellation of Ursa minor being so placed that the principal star, at the tip of the bear's tail, is close to the pole, the diurnal motion of the sphere causes the figure of the bear to swing round the pole feet foremost, as if its tail were nailed to that point. The four successive positions of the constellation at intervals of six hours, are shown in fig. 3, p. 161.

The star β of this constellation, situate on the head of the bear, and therefore more distant from the pole, is easily seen to revolve round the pole as a centre, so that this constellation was regarded as a great celestial clock, and before the advancement of science furnished mariners with other and better means, it was of great use in navigation.

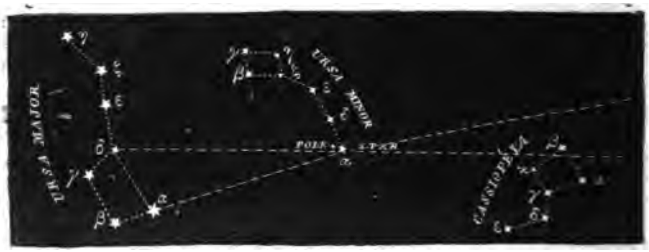
The constellation of the Great Bear being in the quarter of the heavens opposite to that in which the sun is found in the beginning of September, it will be seen on the meridian not far south of the zenith at that season in these latitudes, at midnight.

It will, on the contrary, be on the meridian a little above the horizon at midnight, in the beginning of March. The most favourable times, therefore, for observations upon it, are the months of summer and autumn.

20. A circle described round the north celestial pole, including within it a certain extent of the heavens is called the *Arctic* circle, from the Greek word Ἄρκτος, "arktos," signifying *a bear*, that being, as it were, the region of the bears.

21. To extend the method of pointers to the discovery of the position of other constellations, let us suppose a line carried from the star δ of Ursa major to the pole star, and continued beyond the pole star to an equal distance; this line will then arrive at a well-known constellation called *Cassiopeia's chair*. This constellation consists of several stars, six of which being the most conspicuous are shown in fig. 4. Four of these α, β, κ, and γ, formed the legs and seat, and the two others δ and ε the back.

Fig. 4.



If the line drawn from α of Ursa major through the pole star be continued beyond the latter nearly in a direct line, it will arrive at a constellation called *Pegasus*, which will be easily recognised by four brilliant stars forming a quadrangle very similar to that already described in the constellation of Ursa major. This quadrangle with its position relatively to the pole star, and the line proceeding through that star from the pointers is shown in fig. 5.

22. Of these four stars, three only properly belong to the constellation called *Pegasus;* these three being β, α, and γ, forming the upper right hand corner of the quadrangle. The fourth star, marked also α, belongs to an adjacent constellation called *Andro-*

meda, three of the principal stars of which, marked α, β, and γ, are shown in the figure. By continuing the line of these stars slightly curved, we arrive at another conspicuous star about as far from γ as γ itself is from β. This last is the principal star α of the constellation called Perseus.

Fig. 5.

23. The seven bright stars, here described, three of which belong to the constellation Pegasus; three others to Andromeda, and the fourth to Perseus, have a configuration strikingly similar to that of the seven principal stars of Ursa major, as will be easily perceived by fig. 4.

A second bright star, belonging also to the constellation of Perseus, familiarly known in stellar astronomy by the name of *Algol*, is also shown in the figure; it makes a right angle with the other star α of Perseus, and the star γ of Andromeda.

24. If a line be drawn from the star γ of Pegasus, through the star γ of Andromeda, and continued to an equal distance beyond the latter, it will arrive at a splendid star of the first magnitude called *Capella*, being the principal star of the constellation called *Auriga*. This star, and its relative position to the others, is also shown in the figure.

25. A general view of the stars included within the region of the firmament which we have now traced is exhibited in fig. 6, so as to enable the student to perceive at a single view all the stars which have been just indicated. Six of the principal stars of Ursa major appear at the upper right hand angle of the figure,

and lines are drawn in various directions connecting the principal stars, to show the student the manner of tracing the position of those which he seeks, from those which he already knows. It is

Fig. 6.

assumed that he is already so familiar with the principal stars of Ursa major and the pole star, that he can at once distinguish them. Besides the connecting lines already mentioned, he will see that the position of Algol can be ascertained by a straight line drawn from the star η of Ursa major, and continued to nearly an equal distance beyond the pole star. The star Capella can also be found by following the direction of a line through γ and α of Ursa major, as shown in the figure. If a line be imagined to be drawn through γ and δ of Ursa major, and continued onwards to a distance from δ equal to the distance between the pole star and Pegasus, it will arrive at the principal star of the constellation *Lyra*, called *Vega*; and, if a line be drawn from this star at right angles to the former, it will arrive at the principal star of the constellation of *Cygnus*, generally known as α *Cygni*, but also called *Adrided.*

If a line be drawn through the stars α of Andromeda and β of Pegasus, and be continued through the latter to a distance equal to about four times the distance between these stars, it will arrive at another conspicuous star of the first magnitude, shown in the figure, called *Altair*, being the principal star of the constellation *Aquila* or *the Eagle.*

26. The most magnificent constellation of the firmament, surpassing not only in splendour, but in the almost countless number of its component stars, profusely sprinkled also with nebulæ, as will hereafter appear, is Orion, the principal stars of which are shown in fig. 7, and will be immediately recognised by every eye familiar with the appearance of the firmament. This splendid stellar combination, lying across that part of the ecliptic over which the sun passes in December, will always be visible about midnight on the southern meridian in the month of June, and may indeed be viewed with great advantage and facility during the summer and the latter part of spring. The principal stars, when connected by imaginary lines, form a figure resembling that of an hour-glass. The figure from which the constellation takes its name is a mythological personage, celebrated as a giant and a hunter, who after his death was, according to Homer, elevated to the stars (Iliad, lib. xviii. 486; xxii. 29; Od.

Fig. 7.

v. 274,) where he is represented as a giant, with a girdle or belt, a sword, a cloak of lion skin, and a club.

The stars marked α and γ in the figure, are in the shoulders, and those marked κ and β, in the feet. The three central stars, δ ε ζ form the belt.

Manilius, quoted by Admiral Smyth, says of this constellation:—

> "Orion's beams ! Orion's beams !
> His star-gemmed belt and shining blade,
> His isles of light, his silvery streams,
> And gloomy gulfs of mystic shade."

No constellation, continues Admiral Smyth, was more noted among the ancients than this. As it occupies an extensive space in the heavens, this circumstance may have probably given Pindar his notion that Orion was of a monstrous size, and hence the "jugula" of Plautus, the "*Magni pars maxima cœli*" of Manilius, and the "jebber" of the Arabians. When the rage for innovation was more prevalent than at present, it was proposed to invest this constellation with the figure and to confer upon it the name of Nelson; and in 1807, when Napoleon was in the meridian of his power, the University of Leipzic passed a resolution that the stars of the belt and sword should be erected into an independent constellation to be called Napoleon.

Fig. 3.—THE DIURNAL REVOLUTION OF THE CONSTELLATION OF THE LESSER BEAR.

HOW TO OBSERVE THE HEAVENS.

CHAPTER II.

27. Antiquity of the name of Orion.—28. Nebulæ in the constellation Orion. —29. General view of this region of the heavens.—30. Procyon and Sirius.—31. Aldebaran: the Hyades and the Pleiades.—32. The constellations of the zodiac.—33. Use of celestial maps.—34. Use of a celestial globe.—35. To find the place of an object in the heavens.

27. The name of Orion is of high antiquity, occurring in the books of Job, Amos, Ezekiel, and Isaiah. Some commentators contend, however, that the personage figured in the constellation is no other than Nimrod. It was believed that when this constellation was in such a position as to precede the sun in rising, storms and rain ensued, and Orion is hence characterised by such epithets as "Imbrifer," (the bringer of rain;) "Nimbosus," (the cloudy;) and "Aquosus," (the watery). The Latin poets overflow

with invectives against the pluviosus et tristis Orion; with Horace, he is the "nautis infestus;" with Propertius, the "aquosus;" and with Pliny, the "horridus sideribus."

Two of the four principal stars, those marked α and β in the figure, are of the first magnitude, the former being generally called by the proper name, *Betelgeux*, and the latter, *Rigel*.

The three stars forming the belt are of the second magnitude, and have been popularly known by different names, such as "Jacob's staff," the "yard wand," and the "three kings."

28. The star marked θ in the figure, situate midway between the three stars of the belt and the two stars of the feet, proves to be a very remarkable object when submitted to examination with adequate telescopic power. It is not one, but five stars, combined in close juxta-position; and is moreover surrounded by one of the most remarkable nebulæ in the firmament. These are points, however, which do not fall within the limits of this Tract, but to which we will return on another occasion.

29. To present to the student a collective view of the conspicuous stars and constellations which have been above described, we have given, in fig. 8, a view of a portion of the firmament within which they are included. If the student imagine himself directing his view to the heavens, with his face to the north, on any night about the middle of June, at or near the hour of midnight, he will see above him the stars and constellations indicated in the upper half of the figure; and, if he turn with his face to the south, he will see those included in the lower half. Immediately above his head, and close to the zenith, he will see the splendid star *Capella*; if he carry his eye from the pole star through Capella, towards the south, he will recognise at once the constellation of Orion, which we have just described. The centre star of the belt will be due south. The bright star Betelgeux will be to the right, and Rigel to the left of the meridian; that is, the former will be west and the latter east of the meridian. If he carry his eye in a direct line from the stars ε and δ of Ursa major, he will arrive at the bright star *Pollux* in the constellation *Gemini*, and beside it will see the still brighter star *Castor*, of the same constellation, the latter being of the first, and the former of the second, magnitude.

30. If the same line, directed from the stars of Ursa major through Pollux, be continued nearly in the same direction, it will arrive at *Procyon*, a star of the first magnitude in the constellation of *Canis minor*.

If an equilateral triangle be imagined to be formed upon the south side of the line joining Procyon with Betelgeux, its vertex will fall upon *Sirius*, a star of the first magnitude and the

Fig. 8.—GENERAL VIEW OF THE REGION AROUND THE STAR CAPELLA, INCLUDING THE CONSTELLATION OF ORION.

brightest in the firmament, being the principal star of the constellation of *Canis major*, and thence often called the *Dog Star*. Indeed, this star, from its extraordinary splendour, will be recognised at once by the eye, without the necessity of tracing its position by pointers.

31. If a line be imagined to be drawn from Sirius to the star γ, called *Bellatrix*, in the shoulder of Orion, and continued beyond that point to about half the distance between these stars, it will arrive at a conspicuous star of the first magnitude, called *Aldebaran*, in the constellation of Taurus. This star is placed in the southern eye of the bull, and the three stars of Orion's belt may be considered also as pointers to it.

The constellation of Taurus, of which Aldebaran is the principal star, is remarkable for two splendid clusters visible to the naked eye, and which, being known to the ancients, were called the Hyades and the Pleiades; the former group is in immediate juxtaposition with the eye of the bull, and the latter is in its neck. The mythological origin of these constellations is, as commonly given, as follows:—The Hyades were the daughters of Atlas and Pleione, whose brother Hyas being torn to pieces by a bull, they were overwhelmed with grief, and are said to have wept so incessantly, that the gods in compassion took them into heaven and placed them near the bull's eye, where they still continue to weep; and, accordingly, it was a popular superstition that when they rise immediately before the sun, wet weather ensues. Indeed, the name Hyades is derived immediately from a Greek word 'Υάδες, (Hyades), which signifies the "rainers."

The Pleiades, also daughters of Atlas and Pleione, and therefore sisters of the Hyades, were seven in number; six being visible and the seventh invisible. The seventh was called Sterope, and it was related that she became invisible because, while her sisters had all consorted themselves with gods, she alone yielded to Sisyphus, a mortal. According to other traditions, the seventh Pleiad was called Electra, and her disappearance was explained by her grief at the destruction of the house of Dardanus. The Pleiades are said to have destroyed themselves from grief at the death of their sisters the Hyades. They were afterwards placed among the stars, where they formed a cluster resembling a bunch of grapes, whence they were sometimes called Βότρυς (Botrus). The rising of these stars before the sun, like that of the Hyades, was considered to forebode rain.

If the line of the pointers drawn to the pole star be a little deflected to the left and continued onwards, it will arrive at a remarkable star of the first magnitude, shown in the figure, called α *Cygni*, being the principal star in the constellation of Cygnus.

This star is sometimes called *Adrided;* it was called by the Arabians *Deneb.*

32. Every one is familiar with the fact that, in the course of a year, the sun appears to move round a great circle of the heavens called the *Ecliptic*, and in so doing passes through a series of constellations which lie in that route. The stars composing these are generally included within a zone extending to 10° or 12° on each side of the ecliptic. This zone is called the *Zodiac*, from the Greek word Ζώδιον (Zodion), which signifies a small painted or carved figure of an animal, the zodiac being filled with a series of constellations, to which the names and forms of animals were given. The twelve well-known zodiacal constellations are:—

	Sign.		Sign.
1. Aries (the ram)	♈	7. Libra (the balance)	♎
2. Taurus (the bull)	♉	8. Scorpio (the scorpion)	♏
3. Gemini (the twins)	♊	9. Sagittarius (the archer)	♐
4. Cancer (the crab)	♋	10. Capricornus (the goat)	♑
5. Leo (the lion)	♄	11. Aquarius (the waterman)	♒
6. Virgo (the virgin)	♍	12. Pisces (the fishes)	♓

The signs here annexed to the names are abridged means of expressing not the constellations, but the successive divisions of the ecliptic to which the constellation corresponded at the time they received their names. It must here be explained, that by a peculiar change which has taken place in the annual path of the sun through the heavens, that luminary does not now follow precisely the same course which it followed in remote ages. The position of the sun on the day of the equinox is subject to a small change from year to year, which, though insignificant in short intervals of time, becomes very considerable when it accumulates for ages. Thus, when the constellations of the zodiac received their names, the sun entered the constellation Aries on the day of the spring equinox; but, owing to the cause just explained, the moment at which it entered that constellation became from year to year later and later, until, after the lapse of many centuries, it did not enter Aries till a month after the day of the equinox. During the first month after the equinox the sun is therefore at present in the constellation of Pisces, and not in that of Aries.

As there were twelve zodiacal constellations, the ecliptic in which the sun revolves was divided into twelve equal arcs of 30° each, which were called *signs*, the first 30° commencing from its position on the day of the equinox, was called the sign *Aries*, the second *Taurus*, and so on. And although, owing to the change of position of the ecliptic already indicated, the positions of the constellations from which these signs have taken their names have changed so that, in fact, the constellation Pisces is found in the first sign, and Aries in the second, and so on; the signs have, nevertheless, retained their names.

It is therefore important that the astronomical amateur should not confound the name of the *sign* with the name of the constellation. The *sign* Aries is the first 30° of the ecliptic, while the *constellation* Aries is a group of stars, at present situate between the 30th degree and 60th degree of the ecliptic.

The ancients recognised, besides the twelve zodiacal constellations, twenty-one constellations in the northern, and fifteen in the southern hemisphere. The progress of stellar discovery has, however, augmented considerably these somewhat arbitrary groups of stars, and the number of constellations now recognised amounts to 117, of which 62 are in the northern hemisphere.

33. From all that has been explained above, the student will be able to appreciate the benefit to be derived from having in his possession a collection of celestial maps. Many such have been published, among which may be mentioned more particularly those prepared under the superintendence of the Society for the Diffusion of Useful Knowledge. I have found, however, one of the most convenient for general purposes, "The Guide to the Stars." * In the maps there given, will be found indications of the most useful applications of the method of pointing.

34. A celestial globe may be defined to be a working model of the heavens. It is mounted like a common terrestrial globe. The visible hemisphere is bounded by the horizontal circle in which the globe rests. The brass circle at right angles to this, is the celestial meridian. The constellations, with outlines of the imaginary figures from which they take their names, are delineated upon it.

The globe will serve, not merely as an instrument of instruction, but will prove a ready and convenient aid to the amateur in astronomy, superseding the necessity of many calculations which are often discouraging and repulsive, however simple and easy they may be to those who are accustomed to such inquiries. Most of the almanacs contain tables of the principal astronomical phenomena, of the places of the sun and moon, and of the principal planets as well as the times when the most conspicuous stars are on the meridian after sunset. These data, together with a judicious use of the globe and a tolerable telescope, will enable any person to extend his acquaintance with astronomy, and even to become a useful contributor to the common stock of information which is now so fast increasing by the zeal and ability of private observers in so many quarters of the globe.

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* Twelve Planispheres, forming a Guide to the Stars for every Night in the Year, with an Introduction.—*Taylor and Walton*, London.

To prepare the globe for use, let small marks (bits of paper gummed on will answer the purpose) be placed upon it, to indicate the positions of the sun, moon, and planets, at the time of observing the heavens. The place of the sun on the ecliptic is usually marked on the globe itself. If not, its right ascension (that is, its distance from the vernal equinoxial point, measured on the celestial equator), and its declination (that is, its distance north or south of the equator), are given in the almanac, for every day. The moon's right ascension and declination are likewise given.

35. *To find the place of an object on the globe when its right ascension and declination are known.*—Find the point on the equator where the given right ascension is marked. Turn the globe on its axis till this point be brought under the meridian. Then count off an arc of the meridian (north or south of the equator, according as the declination is given) of a length equal to the given declination, and the point of the globe immediately under the point of the meridian thus found, will be the place of the object. By this rule, the position on the globe of any object of which the right ascension and declination are known, may be immediately found, and a corresponding mark put upon it.

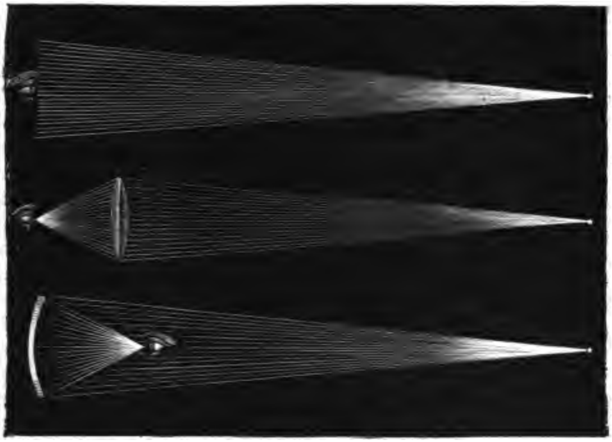
To adjust the globe so as to use it as a guide to the position of objects on the heavens, and as a means of identifying the stars and learning their names, let the lower clamping-screw of the meridian be loosened, and let the north pole of the globe be elevated by moving the brass meridian until the arc of this meridian between the pole and the horizon be equal to the latitude of the place of observation. Let the clamping-screw be then tightened, so as to maintain the meridian in this position. Let the globe be then so placed that the brass meridian shall be directed due north and south, the pole being turned to the north. This being done, the globe will correspond with the heavens so far as relates to the poles, the meridian, and the points of the horizon.

To ascertain the aspect of the firmament at any hour of the night, it is now only necessary to turn the globe upon its axis until the mark indicating the place of the sun shall be under the horizon in the same position as the sun itself actually is at the hour in question. To effect this, let the globe be turned until the mark indicating the position of the sun is brought under the meridian. Observe the hour marked on the point of the equator which is then under the meridian. Add to this hour the hour at which the observation is about to be taken, and turn the globe until the point of the equator on which is marked the hour resulting from this addition is brought under the meridian. The position of the globe will then correspond with that of the firmament. Every object on the one will correspond in its position with its representative mark or symbol on the other. If we imagine a line drawn from the centre of the globe through the mark upon its surface indicating any star, such a line, if continued outside the surface toward the heavens, would be directed to the star itself.

For example, suppose that when the mark of the sun is brought under the meridian, the hour 5h. 40m. is found to be on the equator at the meridian, and it is required to find the aspect of the heavens at half-past ten o'clock in the evening.

	H.	M.
To	5	40
Add	10	30
	16	10

Let the globe be turned until 16h. 10m. is brought under the meridian, and the aspect given by it will be that of the heavens.



Figs. 2, 3, 4.

THE STELLAR UNIVERSE.

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CHAPTER I.

1. Retrospect of the solar system.— 2. Inquiries beyond its limits.— 3. This system surrounded by an extensive void.—4. This proved by the absence of external perturbations.—5. And by comets, which are feelers of the system.—6. Where then is the vast multitude of stars which appear in the firmament?—7. Absence of apparent parallax.—8. Illustration of the effects of parallax.—9. Its apparent absence favoured the Ptolemaic system. — 10. Effects of parallax explained.—11. Parallax of the planets visible.

1. In former parts of this series, we have taken a survey of the group of globes which, in company with the earth, revolve round the sun; have reviewed their motions, compared their magnitudes and distances, and explained the numerous analogies having the force of a moral demonstration which prove that they are inhabited worlds, playing in the economy of the universe parts in all respects similar to that of the earth. Passing successively from planet to planet, we have been oppressed by the stupendous dimensions presented to our contemplation. We have seen Jupiter—a globe fourteen hundred times the bulk of the earth—revolving at a distance of five hundred millions of miles from the sun, attended by his four moons:—the Saturnian system, with its globe, a thousand times more voluminous than that of the earth, its vast rings whirling round it, concentrically with each other and with the planet, and shining upon either hemisphere, having the appearance of a

broad silver zone, and its seven moons. We have seen this complex system, sweeping round the sun in a vast orbit, at a distance of a thousand millions of miles, yet preserving such order in its movements that no one member of it overtakes or is overtaken by another,—the planet having a year thirty times the length of ours, diversified by similar seasons, having variations of temperature within limits equal to those of the earth, but varied by seven different kinds of months. Passing to still more remote distances, we encountered Uranus, attended by moons, the number of which has not been ascertained, and probably furnished with other illuminating apparatus, the discovery of which is reserved for future observers. Revolving at eighteen hundred and twenty millions of miles from the sun, we have shown that this planet has a year eighty-four times the length of ours, diversified no doubt by similar seasons, and that, by reason of its enormous distance, the sun appears to its inhabitants as a disc whose diameter is nineteen times less than that which it presents to us.

In fine, having arrived at the extreme limits of the system, we found the planet Neptune, revolving at the distance of two thousand eight hundred and fifty millions of miles from the sun, having a year a hundred and sixty-four times longer than ours. Thus, the seasons of this planet have each forty-one years' duration. By reason of its distance, the apparent diameter of the sun, as seen by its inhabitants, is thirty times less than that which it presents to us; so that the sun appears to them with the same magnitude as that which the planet Venus presents to us when seen under the most favourable aspect.

Thus it appears that the solar system, of which our earth is an individual member, is included within a circle something less than six thousand millions of miles in diameter; and the space within this circle has been surveyed with the most marvellous precision by astronomical observers.

2. This region, however, vast as it is, forms but a small portion of that part of the material universe to which scientific inquiry and research have been extended. The inquisitive spirit of man has not rested content within such limits. Taking its stand at the extremities of the system, and throwing its searching glance towards the interminable realms of space which extend beyond them, it still asks—What lies there? Has the Infinite circumscribed the exercise of his creative power within these precincts—and has He left the unfathomable depths of space that stretch beyond them a wide solitude? Has He whose dwelling is immensity, and whose presence is everywhere and eternal, remained inactive throughout regions compared with which the solar system shrinks into a point?

Even though scientific research should have left us without definite information on these questions, the light which has been shed on the Divine character, as well by reason as by revelation, would have filled us with the assurance that there is no part of space, however remote, which must not teem with evidences of exalted power, inexhaustible wisdom, and untiring goodness.

But science has not so deserted us. It has, on the contrary, supplied us with much interesting information respecting regions of the universe, the extent of which is so great that even the whole dimensions of the solar system supply no modulus sufficiently great to enable us to express their magnitude.

It will not then be unprofitable or unpleasing on the present occasion to extend our inquiries into those realms of space, which stretch beyond the limits of our system, and to inquire into the condition of the physical creation there.

3. We are furnished with a variety of evidence, establishing incontestably the fact, that around the solar system, to a vast distance on every side, there exists an unoccupied space; that the solar system stands alone in the midst of a vast solitude. It has been shown that the mutual gravitation of bodies placed in the neighbourhood of each other is betrayed by its effects upon their motions. If, therefore, there exist beyond the limits of the solar system, and within a distance not so great as to render the attraction of gravitation imperceptible, any mass of matter, such as another sun like our own, such a mass would undoubtedly exercise a disturbing force upon the various bodies of the system. It would cause each of them to move in a manner different from that in which it would have moved if no such body existed.

4. Thus it appears that, even though a mass of matter in our neighbourhood should escape direct observation, its presence would be inevitably betrayed by the effects which its gravitation would produce upon the planets. No such effects, however, are discoverable. The planets move as they would move if the solar system were independent of any external disturbing attraction. These motions are such, and such only, as can be accounted for by the attraction of the sun and the reciprocral attraction of the other bodies of the system. The inference from this is, that there does not exist any mass of matter in the neighbourhood of the solar system within any distance which permits such a mass to exercise upon it any discoverable disturbing influence; and that if any body analogous to our sun exists in the universe, it must be placed at a distance so great, that the whole magnitude of our system will shrink into a point, compared with it.

5. But we have other indications of this condition of things.

The solar system is supplied with *feelers*, which it is enabled to throw out into the regions surrounding it to vast distances, and these are endowed with the highest conceivable susceptibility, which would cause them to betray to us the presence in these regions even of masses of matter of very limited dimensions. These feelers are the COMETS, and in particular one called Halley's comet. This body emerges periodically, and makes an excursion into the surrounding regions to a distance of little less than one thousand millions of miles beyond the limits of our system, and returns at regular intervals to the sun. It is a body of extreme levity and tenuity compared even with the smallest planetary masses; it is, therefore, eminently susceptible of the effects of gravitation proceeding from a body external to it.

We shall show, on another occasion, that when this body, once in seventy-five years, departs from our system to make its vast excursion through distant regions of space, the eye of science pursues it along its path, watches its movements, and follows its course. That course is calculated upon the supposition that it is subject to no attraction through the entire range of its orbit except those of the sun and planets, and the calculations of its return are thus made. The time and the place of each of its successive returns have been foretold; and we have found that they have corresponded faithfully with such predictions. It is certain, then, that in its range through space this body has not passed in the neighbourhood of any mass of matter capable of exercising an observable attraction upon it. In fact, it moves exactly as it would move if no material object existed in the creation save those of the solar system itself. It follows, therefore, that all other objects must be too distant from our system to produce any discoverable attraction even on so light a body as this.

6. Yet when, on any clear night, we contemplate the firmament, and behold the countless multitude of objects that sparkle upon it, remembering what a comparatively small number are comprised among those of the solar system, and even of these how few are visible at any one time, we are naturally impelled to the inquiry, Where in the universe are these vast numbers of objects placed?

Very little reflection and reasoning, applied to the consideration of our own position and to the appearance of the heavens, will convince us that the objects that chiefly appear on the firmament must be at almost immeasurable distances. The earth in its annual course round the sun moves in a circle, the diameter of which is about two hundred millions of miles. We, who observe the heavens, are transported upon it round that vast circle. The station from which we observe the universe at one period of the year is, then, two hundred millions of miles from the station from which we view it at another.

7. Now it is a fact, within the familiar experience of every one, that the relative position of objects will depend upon the point from which they are viewed. If we stand upon the bank of a river, along the margin of which a multitude of ships are stationed, and view the masts of the vessels, they will have among each other a certain relative arrangement. If we change our position, however, through the space of a few hundred yards, the relative position of these masts will not be the same as before. Two which before lay in line will now be seen separate; and two which before were separated are now brought into line. Two, one of which was to the right of the other, are now reversed; that which was to the right, is at the left, and *vice versâ;* nor are these changes produced by any change of position of the ships themselves, for they are moored in stationary positions. The changes of appearance are the result of *our own change of position;* and the greater that change of position is, the greater will be the relative change of these appearances. Let us suppose, however, that we are moved to a much greater distance from the shipping; any change in our position will produce much less effect upon the relative position of the masts; perhaps it will require a very considerable change to produce a perceivable effect upon them. In fine, in proportion as our distance from the masts is increased, so in proportion will it require a greater change in our own position to produce the same apparent change in their position.

8. Thus it is with all visible objects. When a multitude of stationary objects are viewed from a distance, their relative position will depend upon the position of the observer; and if the station of the observer be changed, a change in the relative position of the objects must be expected; and if no perceptible change is produced, it must be inferred that the distance of the objects is incomparably greater than the change of position of the observer.

Let us now apply these reflections to the case of the earth and the stars. The stars are analogous to the masts of the ships, and the earth is the station on which the observer is placed. It might have been expected that the magnitude of the globe, being eight thousand miles in diameter, would produce a change of position of the observer sufficient to cause a change in the relative position of the stars, but we find that such is not the case. The stars, viewed from opposite sides of the globe, present exactly the same appearance; we must, therefore, infer that the diameter of the earth is absolutely nothing compared to their distance.

But the astronomer has still a much larger modulus to fall back upon. He reflects, as has been already observed, that he is enabled to view the stars from two stations separated from each other, not by eight thousand miles, the diameter of the earth, but by two hundred millions of miles, that of the earth's orbit. He, therefore, views the heavens on the 1st of January, and views them again on the 1st of July, the earth having in the meanwhile passed to the opposite side of its orbit, yet he finds, to his amazement, that the aspect is the same. He thinks that this cannot be —that so great a change of position in himself cannot fail to make some change in the apparent position of the stars;—that, although their general aspect is the same, yet when submitted to exact examination a change must assuredly be detected. He accordingly resorts to the use of instruments of observation capable of measuring the relative positions of the stars with the last conceivable precision, and he is more than ever confounded by the fact that still no discoverable change of position is found.

9. For a long period of time this result seemed inexplicable, and accordingly it formed the greatest difficulty with astronomers, in admitting the annual motion of the earth. The alternative offered was this; it was necessary, either to fall back upon the Ptolemaic system, in which the earth was stationary, or to suppose that the immense change of position of the earth in the course of half a year, could produce no discoverable change of appearance in the stars; a fact which involves the inference, that the diameter of the earth's orbit must be a mere point compared with the distance of the nearest stars. Such an idea appeared so inadmissible that for a long period of time many preferred to embrace the Ptolemaic hypothesis, beset as it was with difficulties and contradictions.

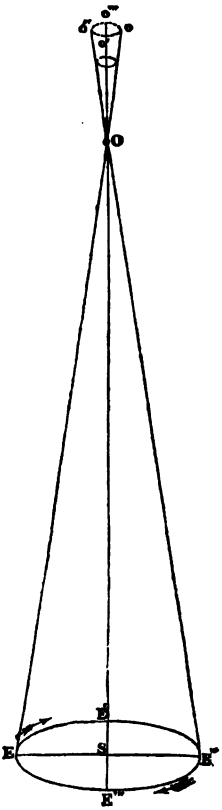
Improved means of instrumental observation and micrometrical measurement, united with the zeal and skill of observers, have at length surmounted these difficulties; and the parallax, small indeed but still capable of measurement, of several stars has been ascertained.

10. To render these results, and the processes by which they have been attained, intelligible, we shall here explain the general effects of annual parallax.

Since the earth moves annually round the sun, as a stationary centre in a circle whose diameter must have the vast magnitude of two hundred millions of miles, all observers placed upon the earth, seeing distant objects from points of view so extremely distant one from the other as are opposite extremities of the same diameter of such a circle, must necessarily, as might be supposed, see these objects in very different directions.

To comprehend the effect which might be expected to be produced upon the apparent place of a distant object by such a motion, let E E′ E″ E‴, fig. 1, represent the earth's annual course round the sun as seen in perspective, and let O be any distant object visible from the earth. The extremity E of the line E O, which is the visual direction of the object, being carried with the earth round the circle E E′ E″ E‴, will annually describe a cone of which the base is the path of the earth, and the vertex is the place of the object O. While the earth moves round the circle E E″, the line of visual direction would therefore have a corresponding motion, and the apparent place of the object would be successively changed with the change of direction of this line. If the object be imagined to be projected by the eye upon the firmament, it would trace upon it a path *o o′ o″ o‴*, which would be circular or elliptical, according to the direction of the object. When the earth is at E, the object would be seen at *o;* and when the earth is at E″, it would be seen at *o″*. The extent of this apparent displacement of the object would be measured by the angle E O E″, which the diameter E E″ of the earth's path or orbit would subtend at the object O.

Fig. 1.



It has been stated that, in general, the apparent displacement of a distant visible object produced by any change in the station from which it is viewed is called PARALLAX. That which is produced by the change of position due to the diurnal motion of the earth being called DIURNAL PARALLAX, the corresponding displacement due to the annual motion of the earth is called the ANNUAL PARALLAX.

The greatest amount, therefore, of the annual parallax for any proposed object is the angle which the semidiameter of the earth's orbit subtends at such object, as the greatest amount of the diurnal parallax is the angle which the semidiameter of the earth itself subtends at the object.

Now, as the most satisfactory evidence of the annual motion of the earth would be the discovery of this displacement, and successive changes of apparent position of all objects on the firmament consequent on such motion, the absence of any such phenomenon must be admitted to constitute, *primâ facie*, a formidable argument against the earth's motion.

11. The effects of annual parallax are observable, and indeed are of considerable amount, in the case of all the bodies composing the solar system. The apparent annual motion of the sun is altogether due to parallax. The apparent motions of the planets and other bodies composing the solar system are the effects of parallax, combined with the real motions of these various bodies.

Until the annual motion of the earth was admitted, these effects of annual parallax on the apparent motions of the solar system were ascribed to a very complicated system of real motions of these bodies, of which the earth was assumed to be the stationary centre, the sun revolving round it, while at the same time the planets severally revolved round the sun as a moveable centre. This hypothesis, proposed originally by Apollonius of Perga, a Grecian astronomer, some centuries before the birth of Christ, received the name of the PTOLEMAIC SYSTEM, having been developed and explained by PTOLEMY, an Egyptian astronomer who flourished in the second century, and whose work, entitled "Syntaxis," obtained great celebrity, and for many centuries continued to be received as the standard of astronomical science.

Although Pythagoras had thrown out the idea that the annual motion of the sun was merely apparent, and that it arose from a real motion of the earth, the natural repugnancy of the human mind to admit a supposition so contrary to received notions prevented this happy anticipation of future and remote discovery from receiving the attention it merited; and Aristotle, less sagacious than Pythagoras, lent the great weight of his authority to the contrary hypothesis, which was accordingly adopted universally by the learned world, and continued to prevail, until it was overturned in the middle of the sixteenth century by the celebrated Copernicus, who revived the Pythagorean hypothesis of the stability of the sun and the motion of the earth.

The hypothesis proposed by him in a work entitled "De Revolutionibus Orbium Cœlestium," published in 1543, at the moment of his death, is that since known as the COPERNICAN SYSTEM, and, being now established upon evidence sufficiently demonstrative to divest it of its hypothetical character, is admitted as the exposition of the actual mevements by which that part of the universe called the solar system is affected.

Fig. 62.—TELESCOPIC VIEW OF PART OF THE GREAT NEBULA IN THE CONSTELLATION OF ARGO.

THE STELLAR UNIVERSE.

CHAPTER II.

12. Absence of parallax obstructed the acceptance of the Copernican system.—13. Immense distance of stars inferred from its minuteness or absence.—14. Its greatest possible magnitude.—15. Distances of stars inferred.—16. Use of the motion of light as a modulus of this distance.—17. Methods of ascertaining the parallax.—18. Parallax of α Centauri.—19. Parallax of nine principal stars.—20. The vacuum surrounding the solar system necessary to cosmical order.—21. Classification of stars by magnitude arbitrary.—22. Fractional magnitudes.—23. Number of stars of each magnitude.—24. Total number of stars in the firmament.—25. Varieties of magnitude chiefly caused by difference of distance.—26. Stars as distant from each other as from the sun.—27. Telescopes do not magnify them.—28. Absence of a disc proved by their occultations.—29. Meaning of the term magnitude as applied to the stars.—30. Why the stars may be rendered imperceptible by their distance.—31. Real magnitudes of the stars.—32. Application of photometers or astrometers.—33. Comparison of the sun's light with that of a star.—34. Relative real magnitudes of the sun and a star estimated.—35. Comparative magnitude of the sun and the dog-star.—36. Vast use of the telescope in stellar observations.—37. Its power to increase the apparent splendour of a star explained.

12. The greatest difficulty against which the Copernican system has had to struggle, even among the most enlightened of its oppo-

nents, has been the absence of all apparent effects of parallax among the fixed stars, those objects which are scattered in such countless numbers over every part of the firmament. From what has been explained, it will be perceived that, supposing these bodies to be, as they evidently must be, placed at vast distances outside the limits of the solar system, and in every imaginable direction around it, the effects of annual parallax would be to give to each of them an apparent annual motion in a circle or ellipse, according to their direction in relation to the position of the earth in its orbit, the ellipse varying in its eccentricity with this position, and the diameter of the circle or major axis of the ellipse being determined by the angle which the diameter E E" (fig. 1) of the earth's orbit subtends at the star, which will be less the greater the distance of the star, and *vice versâ*. The apparent position of the star in this circle or ellipse would be evidently always in the plane passing through the star and the line joining the sun and earth.

13. Since then, with a few exceptions, which will be noticed hereafter, no traces of the effects of annual parallax have been discovered among the innumerable fixed stars by which the solar system is surrounded; and since, nevertheless, the annual motion of the earth in its orbit rests upon a body of evidence, and is supported by arguments which must be regarded as conclusive, the absence of parallax can only be ascribed to the fact, that the stars generally are placed at distances from the solar system, compared with which the orbit of the earth shrinks into a point; and, therefore, that the motion of an observer round this orbit, vast as it may seem compared with all our familiar standards of magnitude, produces no more apparent displacement of a fixed star, than the motion of an animalcule round a grain of mustard-seed would produce upon the apparent direction of the moon or sun.

The visual ray by which a star is seen, and which is its apparent direction, is carried by the annual motion of the earth round the surface of a cone, of which the earth's orbit is the base, and of which the star is the apex. The line drawn from the centre of the earth's orbit to the star, is the axis of this cone; and, consequently, the parallax of the star is the angle under the latter line, and the visual ray by the motion of which the surface of the cone is formed.

The same optical effect would be produced by transferring the orbital motion of the earth to the star, the observer being supposed to be stationary, and placed at the centre of the earth's orbit; and this supposition will render all the parallactic phenomena much more easily comprehended. Let the star, then, be imagined to move in a circle equal and parallel to the earth's orbit, the centre of the circle being the true place of the star. The place of the star in this circle of parallax must always be diametrically opposite to the corresponding place of the earth in its orbit. The star so moving would suffer exactly the same apparent displacement as it would appear to suffer if it were, as it is, at rest in its true place, the earth moving in its proper orbit round the sun.

14. It might be supposed, that where the character and laws of the phenomena are so clearly understood, the discovery of their existence could present no great difficulty. Nevertheless, nothing in the whole range of astronomical research has more baffled the efforts of observers than this question of the parallax. This has arisen altogether from the extreme minuteness of its magnitude. It is quite certain that the parallax does not amount to so much as 1″ in the case of any of the numerous stars which have been as yet submitted to the course of observation which is necessary to discover the parallax. Now, since in the determination of the exact uranographical position of a star there are a multitude of disturbing effects to be taken into account and eliminated, such as precession, nutation, aberration, refraction, and others, besides the proper motion of the star, which will be explained hereafter; and since, besides the errors of observation, the quantities of these are subject to more or less uncertainty, it will astonish no one to be told that they may entail, upon the final result of the calculation, an error of 1″; and, if they do, it is vain to expect to discover such a residual phenomenon as parallax, the entire amount of which is less than 1″.

15. If in any case the parallax could be determined, the distance of the stars could be immediately inferred. For, if this value of the parallax be expressed in seconds, or in decimals of a second, and if R denote the semidiameter of the earth's orbit, D the distance of the star, and P the parallax, we shall have

$$D = R \times \frac{206265}{P}.$$

If, therefore, $P = 1''$, the distance of the star would be 206265 times the distance of the sun, and since it may be considered satisfactorily proved, that no star which has ever yet been brought under observation has a parallax greater than this, it may be affirmed that the nearest star in the universe to the solar system is at a distance, *at least*, 206265 times greater than that of the sun.

Let us consider more attentively the import of this conclusion. The distance of the sun, expressed in round numbers (which are sufficient for our present purpose), is 95 millions of miles. If this be multiplied by 206265, we shall obtain,—not indeed the distance of the nearest of the fixed stars,—but the *minor limit* of that distance, that is to say, a distance within which the star cannot lie. This limit, expressed in miles, is

$$D = 206265 \times 95,000000 = 19,595175,000000 \text{ miles},$$

or nearly *twenty billions of miles.*

16. In the contemplation of such numbers the imagination is lost, and no other clear conception remains, except of the mere arithmetical expression of the result of the computation. Astronomers themselves, accustomed as they are to deal with stupendous numbers, are compelled to seek for units of proportionate magnitude to bring the arithmetical expression of the quantities within moderate limits. The motion of light supplies one of the most convenient moduli for this purpose, and has, by common consent, been adopted as the unit in all computations whose object is to gauge the universe. It is known that light moves at the rate of 192000 miles per second. If, then, the distance D above computed be divided by 192000, the quotient will be the time, expressed in seconds, which light takes to move over that distance. But since even this will be an unwieldy number, it may be reduced to minutes, hours, days, or even to years.

In this manner we find that, if any star have a parallax of 1″, it must be at such a distance from our system, that light would take 3·234 years, or three years and eighty-five days, to come from it to the earth.

If the space through which light moves in a year be taken, therefore, as the unit of stellar distance, and P be the parallax expressed in seconds, or decimals of a second, we shall have

$$D = \frac{3 \cdot 234}{P}.$$

17. It will easily be imagined that astronomers have diligently directed their observations to the discovery of some change of apparent position, however small, produced upon the stars by the earth's motion. As the stars most likely to be affected by the motion of the earth are those which are nearest to the system, and therefore probably those which are brightest and largest, it has been to such chiefly that this kind of observation has been directed; and since it was certain that, if any observable effect be produced by the earth's motion at all, it must be extremely small, the nicest and most delicate means of observation were those alone from which the discovery could be expected.

One of the earlier expedients adopted for the solution of this problem, was the erection of a telescope, of great length and power, in a position permanently fixed, attached, for example, to the side of a pier of solid masonry, erected upon a foundation of rock. This instrument was screwed into such a position that particular stars, as they crossed the meridian, would necessarily pass within its field of view. Micrometric wires were, in the usual manner, placed in its eye-piece, so that the exact point at which the stars passed the meridian each night, could be observed and recorded with the greatest precision. The instrument being thus fixed and immovable, the transits of the stars were noted each night, and the exact places where they passed the meridian recorded. This kind of observation was carried on through the year; and if the earth's change of position, by reason of its annual motion, should produce any effect upon the apparent position of the stars, it was anticipated that such effect would be discovered by these means. After, however, making all allowance for the usual causes which affect the apparent position of the stars, no change of position was discovered which could be assigned to the earth's motion.

18. Notwithstanding the numerous difficulties which beset the solution of this problem, by means of observations made with the ordinary instruments, Professor Henderson, during his residence, as astronomer at the Royal Observatory, at the Cape of Good Hope, succeeded in making a series of observations upon the star designated α in the constellation of the Centaur, which, being afterwards submitted by him to the proper reductions, gave a parallax of 1″. Subsequent observations made by his successor, Mr. Maclear, at the same observatory, partly with the same instrument, and partly with an improved and more efficient one of the same class, have fully confirmed this result, giving 0·9128, or $\frac{10}{11}$ths of a second as the parallax.

It is worthy of remark, that this conclusion of Messrs. Henderson and Maclear is confirmed in a remarkable manner by the fact, that like observations and computations, applied to other stars in the vicinity of α Centauri, and therefore subject to like annual causes of apparent displacement, such as the mean annual variation of temperature, gave no similar result, showing thus that the displacement found in the case of α Centauri could only be ascribed to parallax.

Since the limits of error of this species of observation affecting the final result cannot exceed the tenth of a second, it may then be assumed as proved, that the parallax of α Centauri is 1″, and, consequently, that its distance from the solar system is such that light must take 3·234 years to move over it.

19. Notwithstanding the great multitude of stars to which instruments of observation of unlooked-for perfection, in the hands of the most able and zealous observers, have been directed, the results of all such labours have hitherto been rather negative than positive. The means of observation have been so perfect, and their

application so extensive, that it may be considered as proved by the absence of all measureable displacement consequent upon the orbital motion of the earth, that, a very few individual stars excepted, the vast multitude of bodies which compose the universe, and which are nightly seen glittering in the firmament, are at distances from the solar system greater than that which would produce an apparent displacement amounting to the tenth of a second. This limit of distance is therefore, ten parallactic units, or about two million times the space between the earth and sun.

Within this limit, or very little beyond it, nine stars have been found to be placed, the nearest of which is that already mentioned, of which Professor Henderson discovered the parallax. Those of the others are due to the observations of Messrs. Bessel, Struve, and Peters. In the following table the parallaxes of these stars are given, with their corresponding distances, expressed in parallactic units, and also in the larger unit presented by the distance through which light moves in a year.

The parallax of the first seven of these stars may be considered as having been ascertained with tolerable certainty and precision. The very small amount of that of the last two is such as to render it more doubtful. What is certain, however, in relation to these is, that the actual amount of their parallax is less than the tenth of a second.

TABLE.

Nine stars, with their ascertained parallax and corresponding distances.

Star.	Parallax.	Distance.		Observer.
		Sun's dist.=1.	Annual motion of light=1.	
α Centauri ...	0·913″	225920	3·54217	Henderson.
61 Cygni... ...	0·348	592715	9·29310	Bessel.
α Lyræ	0·261	790287	12·39080	Struve.
Sirius	0·230	896804	14·06087	Henderson.
1830 Groombridge	0·226	912677	14·30973	Peters.
ι Ursæ	0·133	1550864	24·31579	Peters.
Arcturus	0·127	1624134	25·46456	Peters.
Polaris	0·067	3078582	48·26866	Peters.
Capella	0·046	4484021	70·30435	Peters.

It appears, then, that of the vast multitudes of stars to which the labours of observers have been directed, there are not more than nine which are near enough to our system to be sensibly affected in their apparent directions by the orbital motion of the earth; and that the greatest change produced in the direction of any of these, when seen from opposite sides of the earth's orbit, does not amount to quite so much as one second; while, for those least affected, it does not amount to so much as the tenth of a second; and the necessary inference is, that the nearest of the stars which are scattered in such countless numbers over the heavens, is at a distance over which light would take three years and a-half to pass, moving during that interval through two hundred thousand miles in each second of time.

20. The solar system is, consequently, surrounded in every direction, above, below, and on every side, by a vast abyss, in which no masses of matter, bearing any analogy to the sun or planets, are found; and, indeed, the physical necessity of such a surrounding vacuum will be evident, when it is considered that the proximity of any such masses to the solar system would, by reason of their disturbing forces, throw that system into utter confusion; that it would derange the succession and limits of seasons for all the worlds composing it; would expose them to extremes of temperature incompatible with organised life; and would, ere long, bring them into destructive and fatal collision with each other, or with the masses in their neighbourhood.

We see, therefore, that if Omnipotence has withdrawn the exertion of its creative power from the realms of space which immediately surround us, it has not done so without good and beneficent reasons, and that there is as much to admire in the absence of such manifestation of power in these regions, as in its presence elsewhere.

21. The most inattentive observer of the heavens will be struck with the fact, that the multitude of stars which are presented to his view vary extremely in splendour. Some few might be imagined to shed a perceptible light, and are truly magnificent objects, even when viewed only by the naked eye; while others are so minute and faint, as to be barely perceptible. Between these extremes there are infinite gradations; and astronomers, in adopting a classification, encounter the same difficulty as is presented in every other case in which, for the purposes of science, natural objects are required to be distributed in a limited number of distinct groups. Nature has, in all cases, created them as individuals, distinguished one from another by infinitely minute and faint gradations and characters, while our limited faculties compel us to contemplate them, and reason upon them, as though

they existed in distinct classes. Such classification must, therefore, be to a great extent arbitrary, the individuals placed at the bottom of one class being just as well entitled to a place at the top of the next.

Astronomers, accordingly, in the classification of the visible stars, in the order of their relative splendour, have encountered a like difficulty. The ancient astronomers, by common consent, distributed all the stars visible to the naked eye into six orders of what they called magnitude. The most splendid stars were said to be stars of the first magnitude: the next in the order of splendour, of the second magnitude; and so on to the sixth, which included the stars barely perceptible with the naked eye. As may be expected, from what has been stated, much difference between astronomer and astronomer arose in settling this classification. It necessarily occurred, that numerous stars had such brightness as would equally entitle them to be placed at the foot of the stars of the first magnitude, or at the head of those of the second magnitude. A still greater number raised a like question as to their title to a place in the classes of the second and third magnitude, and so on. Notwithstanding these vague and uncertain conditions, the ancient classification has still maintained its place, and has been accepted by modern astronomers as the least inconvenient in principle, and, as will presently appear, they have even extended the principle, defective as it is, to the far more numerous classes of stars which the telescope has rendered visible.

22. An expedient has occasionally been adopted by observers aiming at more than usual precision to distinguish stars whose brightness renders it doubtful to which of two succeeding magnitudes they ought to be assigned, consisting of a fraction annexed to the number which designates the higher of the two orders. Thus, for example, a star whose brightness appears to give it equal titles to be placed at the foot of those of the second, or the head of those of the third magnitude, is designated as a star of the $2\frac{1}{2}$ magnitude.

Modern observers have also extended the ancient classification to seven orders of magnitude; dividing the ancient stars of the sixth magnitude into two, designated the sixth and the seventh magnitudes; so that, according to the classification received at present, the most minute stars visible to the naked eye, under the most favourable atmospheric conditions at midnight, when all interference of solar light is removed, are classed as stars of the seventh magnitude.

We must here, however, observe, that we fall again into the difficulties arising from arbitrary classification, since certain stars are visible to some eyes, which, at the same time and place, are invisible to others without telescopic aid. Strictly speaking, therefore, stars of the seventh magnitude may be considered as holding an intermediate and doubtful place between those which can and those which cannot be seen by the naked eye.

Having thus explained generally the classification of stars according to their relative apparent splendour, we are now to state the total number of each class scattered over the entire firmament.

23. According to the most accredited catalogue, that of Argelander, the total number of stars from the first to the sixth magnitude inclusive, observed in the northern hemisphere, has been as follows:—

1st Magnitude	9
2nd ditto	34
3rd ditto	96
4th ditto	214
5th ditto	550
6th ditto	1439
Total number	2342

24. Owing to the absence of an equal number of observers in southern latitudes, that hemisphere has not been so accurately surveyed; but it has been ascertained, that it contains 914 stars, from the first to the sixth magnitude inclusive, within 36° of the celestial equator. If it be supposed, as is highly probable, that the stars are distributed in the same proportion over the remainder of the southern hemisphere, it will follow that the total number of stars of the first six orders of magnitude, distributed over the entire firmament from pole to pole, amounts to 4100. If to this be added the probable number of stars of the seventh magnitude, which cannot be so exactly ascertained by direct observation, it will appear that the total number of stars, distributed over the heavens of such a magnitude as to be seen by the best eyes, under the most favourable atmospheric circumstances, is about 6000.

The number of these objects, as they would be estimated by a mere coup d'œil of the heavens, would appear to be vastly greater than this; and even the calculations of some astronomers, allowing a much larger number for the stars of the seventh magnitude, make the total double the number we have here assigned to it.

25. Are we to suppose, then, that this relative brightness which we perceive, really arises from any difference of intrinsic splendour between the objects themselves? or does it, as it may equally do, arise from their difference of distance? Are the stars of the seventh magnitude so much less bright and conspicuous

than those of the first magnitude, because they are really smaller orbs placed at the same distance? or because, being intrinsically equal in splendour and magnitude, the distance of those of the seventh magnitude is so much greater than the distance of those of the first magnitude that they are diminished in their apparent brightness? We know that by the laws of optics the light received from a luminous object diminishes in a very rapid proportion as the distance increases. Thus, at double the distance it will be four times less, at triple the distance it will be nine times less, at a hundred times the distance it will be ten thousand times less, and so on.

It is evident, then, that the great variety of lustre which prevails among the stars may be indifferently explained, either by supposing them objects of different intrinsic brightness and magnitude, placed at the same distance; or objects generally of the same order of magnitude, placed at a great diversity of distances.

Of these two suppositions, the latter is infinitely the more probable and natural; it has, therefore, been usually adopted: and we accordingly consider the stars to derive their variety of lustre almost entirely from their places in the universe being at various distances from us.

26. Taking the stars generally to be of intrinsically equal brightness, various theories have been proposed as to the positions which would explain their appearance; and the most natural and probable is, that their distances from each other are generally equal, or nearly so, and correspond with the distance of our sun from the nearest of them. In this way the fact that a small number of stars only appear of the first magnitude, and that the number increases very rapidly as the magnitude diminishes, is easily rendered intelligible.

If we imagine a person standing in the midst of a wood, surrounded by trees on every side and at every distance, those which immediately surround him will be few in number, and by proximity will appear large. The trunks of those which occupy a circuit beyond the former, will be more numerous, the circuit being wider, and will appear smaller, because their distance is greater. Beyond these again, occupying a still wider circuit, will appear a proportionally augmented number, whose apparent magnitude will again be diminished by increased distance; and thus the trees which occupy wider and wider circuits at greater and greater distances will be more and more numerous, and will appear continually smaller. It is the same with the stars; we are placed in the midst of an immense cluster of suns, surrounding us on every side at inconceivable distances. Those few which are placed immediately about our system, appear bright and large, and we call them *stars of the first magnitude*. Those which lie in the circuit beyond, and occupy a wider range, are more numerous and less bright; and we call them stars of the second magnitude. And there is thus a progression increasing in number and distance and diminishing in brightness, until we attain a distance so great that the stars are barely visible to the naked eye. This is the limit of vision. It is the limit of the range of the eye in its natural condition; but an eye has been given us more potent still, and of infinitely wider range,—the eye of the mind. The telescope, a creature of the understanding, has conferred upon the bodily eye an infinitely augmented range, and, as we shall presently see, has enabled us to penetrate into realms of the universe, which, without its aid, would never have been known to us. But let us, however, pause for the present, and dwell for a moment upon that range of space which comes within the scope of natural vision.

27. A planet, to the naked eye, with one or two exceptions, appears like a common star. The telescope, however, immediately presents it to us with a distinct circular disc, similar to that which the moon offers to the naked eye; and in the case of some of the planets, a powerful telescope will render them apparently even larger than the moon. But the effect is very different indeed when the same instrument is directed even to the brightest star. We find that instead of magnifying, it actually diminishes. There is an optical illusion produced when we behold a star, which makes it appear to us to be surrounded with a radiation which causes it to be represented, when drawn on paper, by a dot with rays diverging on every side from it. The effect of the telescope is to cut off this radiation, and present to us the star as a mere *lucid point*, having no sensible magnitude; nor can any augmented telescopic power which has yet been resorted to, produce any other effect. Telescopic powers, amounting to 6000, were occasionally used by Sir William Herschel, and he stated that with these the apparent magnitude of the stars seemed *less*, if possible, than with lower powers.

28. We have other proofs of the fact, that the stars have no sensible discs, among which may be mentioned the remarkable effect called the occultation of a star by the dark edge of the moon. When the moon is a crescent, or in the quarters, as it moves over the firmament, its dark edge successively approaches to, or recedes from, the stars. And from time to time it happens that it passes between the stars and the eye. If a star had a sensible disc in this case, the edge of the moon would gradually cover it, and the star, instead of being instantaneously extinguished, would gradually disappear. This is found not to be the case;

the star preserves all its lustre until the moment it comes into contact with the dark edge of the moon's disc, and then it is instantly extinguished, without the slightest appearance of diminution of its brightness.

29. It may be asked then, if such be the case, and if none of the stars, great or small, have any discoverable magnitude at all, with what meaning can we speak of stars of the first, second, or other orders of magnitude? The term magnitude thus applied, was used before the invention of the telescope, when the stars, having been observed only with the naked eye, were really supposed to have different magnitudes. We must accept the term now to express, not the comparative magnitude, but the comparative brightness of the stars. Thus, a star of the first magnitude means of the greatest apparent brightness; a star of the second magnitude, means that which has the next degree of splendour, and so on. But what are we to infer from this singular fact, that no magnifying power, however great, will exhibit to us a star with any sensible magnitude? must we admit that the optical instrument loses its magnifying power when applied to the stars, while it retains it with every other visible object? Such a consequence would be eminently absurd. We are therefore driven to an inference regarding the magnitude of stars, as astonishing and almost as inconceivable as that which was forced upon us respecting their distances. We saw that the entire magnitude of the annual orbit of the earth, stupendous as it is, was nothing compared to the distance of one of those bodies, and, consequently, if that orbit were filled by a sun, whose magnitude would therefore be infinitely greater than that of ours, such a sun would not appear to an observer at the nearest star of greater magnitude than 1″; consequently, would have no magnitude sensible to the eye, and would appear as a mere lucid point to an observer at the star! We are then prepared for the inference respecting the fixed stars which telescopic observations lead to. The telescope of Sir William Herschel, to which he applied a power of 6000, did undoubtedly magnify the stars 6000 times, but even then their apparent magnitude was inappreciable. We are then to infer that the distance of these wonderful bodies is so enormous, compared with their actual magnitude, that their apparent diameter, seen from our system, is above 6000 times less than any which the eye is capable of perceiving.

30. It appears, therefore, that stars are rendered sensible to the eye, not by subtending a sensible angle, but by the light they emit. It has been already explained,* that an illuminated or

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* See Tract on "The Eye."

luminous object—such, for example, as the sun—has the same apparent brightness at all distances; and, consequently, that the quantity of light which the eye of an observer receives from it being in the exact ratio of the apparent area of its visible disc, is inversely as the square of its distance. It remains, however, to explain how it can be that, after it ceases to have a disc of sensible diameter, it does not cease to be visible. This arises from the fact, that the luminous point constituting the image on the retina, is intrinsically as bright as when that image has a large and sensible magnitude. The eye is therefore sensible to the light, though not sensible to the magnitude of the image; and it continues to be sensible to the light, until by increase of distance the light which enters the pupil, and is collected on the retina, though still as intense in its brilliancy as before, is so small in its *quantity*, that it is insufficient to produce sensation.

31. Since it is certain that no body shining like a planet, with borrowed light, could be visible at all, even with the aid of a telescope, at distances far less than those which intervene between the solar system and the nearest of the stars, it follows that the stars must be self-shining bodies like our sun; or, what is the same, that our sun is only one individual unit of the vast number of stars, which are scattered through the universe. This being admitted, a question of much interest and importance arises, to determine not merely the distance of our sun from surrounding suns, and the distances of surrounding suns from each other, but also the comparative magnitude or splendour of these numerous suns, relatively to our own and to each other.

32. One of the most essential data for the solution of this problem, is a sufficiently exact numerical estimate of the comparative apparent lustre of the stars as they appear to the eye, relatively to the sun and to each other. Various instruments have accordingly been invented called *Photometers* or *Astrometers*, which have attained this object with more or less precision. Without entering into the details of the principle or construction of such instruments, we may here state that by their means, the proportion of the quantity of light transmitted to the eye by the sun or moon, or by either of these objects, and a star, or by different stars, compared together, can be ascertained.

By such means, Sir J. Herschel compared the full moon with certain fixed stars, and ascertained, by a mean of eleven observations, that its lustre bore to that of the star α Centauri, which he selected as the standard star of the first magnitude, the ratio of 27408 to 1; in other words, he showed that a cluster consisting of 27408 stars equal in brightness to that of α Centauri would give the same light as the full moon.

Dr. Wollaston, by certain photometric methods, which are considered to have been susceptible of great precision, compared the light of the sun with that of the full moon, and found that the ratio was 801072 to 1; or in other words, that to obtain moonlight as intense in its lustre as sun-light, it would be necessary that 801072 full moons should be stationed in the firmament together.

33. By the combination of these observations of Herschel and Wollaston, we are supplied with means of bringing into direct numerical comparison the sun and the star α Centauri. Since it appears that the light of α Centauri is 27408 times less than that of the full moon, while the light of the full moon is 801072 times less than that of the sun, it will evidently follow, that the light received by the eye from the sun, is greater than that received from the star in the proportion of 801072 times 27408 to 1. Thus, it appears that the light received from the sun, is in round numbers 21956 million times the light received from this particular star, which has been adopted as a fair average standard of stars of the first magnitude.

34. It has been demonstrated by theory, and verified by experiment, that when a luminous object is removed from the eye to increasing distances, the light which the eye receives from it will decrease in the same proportion as the square of the distance increases: that is, at twice the distance, the light is decreased to one fourth; at three times the distance, to a ninth; at four times the distance, to a sixteenth, and so on.

Now, upon this principle, it will be easy to compute the proportion in which the apparent light of the sun would be diminished by any given increase of distance; or, what increase of distance would produce any given decrease of light. Let it then, be demanded how far the sun should be removed from the observer, in order that its light should be decreased in the proportion of 21956 millions to 1, that is so that its light should be equal to that of the star α Centauri. According to what has been just explained, this increase of distance will be found by taking the square root of 21956 millions, which is 148175. It follows, therefore, that if the sun were removed to 148175 times its present distance, it would appear as a star precisely similar to the star α Centauri.

But it has been already shown that this particular star is at a distance 225920 times that of the sun, and, consequently, it follows, that if the sun were removed to that distance, its lustre would be less than that of α Centauri, in the proportion of the square of 148175 to the square of 225920, which is in the proportion of 22 to 51.

Since then, the sun placed beside the star α Centauri, both being at the same distance from the observer, would appear less bright than the star in the proportion of 22 to 51, or 1 to 2⅓, it follows, that the star α Centauri is a sun more than twice the superficial magnitude of ours, supposing that its luminous surface has the same lustre.

35. Sir J. Herschel found that the lustre of the dog-star is four times that of α Centauri; but according to what has been given in the table in page 182, the distance of the dog-star called *Sirius*, from our system is 896087 times that of the sun. Now from these data, it will be easy to calculate the relative magnitudes of our sun and the dog-star.

Since the light received from the dog-star is four times that received from α Centauri, while the light received from the latter is 21956 million times less than that received from the sun, it follows, that the light received from the dog-star is 5489 million times less than the light received from the sun. Let us now imagine the sun removed to the distance of the dog-star, and let us consider what would then be the light received from it. The distance of the dog-star being 896087 times that of the sun, the sun removed to that distance, would shine with a light less than its present light, in the proportion of the square of 896087 to 1, which is in the proportion of 802972 millions to 1. But from what has been stated above, it appears that the dog-star at the same distance, shines with a light less than the sun in the proportion of 5489 millions to 1. It follows, therefore, that the sun and the dog-star, being placed at the same distance from the observer, the lustre of the dog-star would exceed that of thesun in the proportion of 802972 to 5489, or 146¼ to 1;[*] from which we arrive at the surprising conclusion, that, supposing the surface of Sirius to have a lustre equal to that of the surface of the sun, its surface must be 146¼ times greater than that of the sun, so that this stupendous globe of light would have a diameter 12·09 times greater than that of our sun; and, since the diameter of the latter is 882000 miles, that of Sirius would be 10,663380 miles.

36. Since no telescope, however great might be its power, has ever presented a fixed star with a sensible disk, it might be inferred that, for the purposes of stellar investigations, the importance of that instrument must be inferior to that which it may claim in other applications. Nevertheless it is certain, that in no department of physical science has the telescope produced such

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[*] Sir John Herschel makes the proportion 63·02, which is certainly incorrect, that being the ratio of the brightness of Sirius to that of α Centauri, and not that of Sirius to the sun; see Herschel's Astronomy, p. 553, edition 1849.

wonderful results as in its application to the analysis of the starry heavens.

Two of the chief conditions necessary to distinct vision are, first, that the image on the retina shall have sufficient magnitude; or, what is equivalent to this, that the object or its image shall subtend at the eye a visual angle of sufficient magnitude; and, secondly, it must be sufficiently illuminated. When, by reason of their distance from the observer, visible objects fail to fulfil either or both of these conditions, the telescope is capable of re-establishing them. It augments the visual angle by substituting for the distant object, which the observer cannot approach, an optical image of it close to his eye, which he can approach; and it augments the illumination by collecting, on each point of such image, as many rays as can enter the aperture of the object glass, instead of the more limited number which can enter the pupil of the naked eye; allowance, nevertheless, being made for the light lost by reflection from the surfaces of the lenses, and by the imperfect transparency of their material.

37. Although no telescope hitherto constructed has ever presented to an observer the optical image of a star, so as to be seen with any sensible visual angle, such image always appearing as a mere lucid point, it is capable, nevertheless, of increasing the brilliancy of that point in an immense proportion. The way in which it accomplishes this, is easily explained. If the eye be imagined to be directed to a star, as shown in fig. 2, the number of rays diverging from that star, and consequently its apparent brightness, will be limited by, and proportional to the magnitude of the pupil. But if the pencil of rays, before arriving at the eye, be received upon the object glass of a refracting telescope, as shown in fig. 3, or upon the concave reflector of a reflecting telescope, as shown in fig. 4, they will be made to converge to a point, and by proper expedients, the eye being placed near that point, instead of receiving only so many rays, as are proportionate to the dimensions of the pupil, will receive all, or nearly all the rays which pass through the object glass, or which are reflected from the concave speculum. Thus, the intensity of the light received from the object will, by such an instrument, be augmented very nearly in the proportion of the square of the diameter of the pupil to the square of the diameter of the object glass or speculum. Taking, for example, the diameter of the object-glass at 12 inches; and that of the pupil a little less than the eighth of an inch, the former will be about 100 times the latter; and it will consequently augment the light received by the eye, in the proportion of about 10000 to 1.

Fig. 52.*

A ROUND NEBULA, OBSERVED AND DRAWN BY SIR J. HERSCHEL.

Fig. 53.*

THE SAME OBJECT, AS SHOWN IN LORD ROSSE'S GREAT TELESCOPE.

THE STELLAR UNIVERSE.

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CHAPTER III.

38. Telescopic stars.—39. Space-penetrating power of the telescope.—40. Vast distances of small telescopic stars. Periodic Stars: 41. Stars of variable lustre.—42. Remarkable stars of this kind in Cetus and Perseus.—43. Table of periodic stars.—44. Hypothesis to explain Periodic stars. Temporary Stars: 45. Such stars seen in ancient times.—46. Star discovered by Mr. Hind.—47. Missing stars. Double Stars: 48. Researches of Sir W. and Sir J. Herschel.—49. Stars optically double.—50. This supposition not admissible.—51. Refuted by the proper motion.—52. Classification of double stars.—53. Table of double stars.—54. Coloured double stars.—55. Triple and other multiple stars.—56. Attempt to discover parallax by double stars.—57. Observations of Sir W. Herschel.

38. In the preceding paragraphs, our observations have been limited to those stars which are visible to the naked eye. But the power of the telescope to augment in an indefinite proportion the light received by the eye from such an object, obviously supplies the means of rendering stars visible, which, by reason of their extreme distance, transmit light of too small a quantity to affect the retina in any sensible degree. We have seen that stars

* The objects are here drawn upon a larger scale than in the original figures, in order to render their details more distinct. The same enlargement of scale has been made in figs. 17, 18, 19, 20, 29, 30, 41, 42, 43, 44, 45, 46, 57, 58.

of the seventh magnitude are only visible under the most favourable atmospheric conditions, and by the sharpest eyes; now, if we suppose these stars, or others similar to them, to be placed at twice their distance, the light they transmit will be diminished in a fourfold proportion; and since at their actual distance they were barely visible, they will be evidently invisible at the augmented distance. But if we suppose a telescope directed to them, which has the power of increasing the light transmitted to the eye in a fourfold proportion, they will, when seen through it, appear exactly as stars of the seventh magnitude; and if the telescope be capable of increasing the light in a greater proportion, they will appear as stars of a still greater magnitude.

In like manner, if we suppose stars of the seventh magnitude removed to three times their present distance, their light would be diminished in a ninefold proportion. But a telescope which would increase the light transmitted to the eye in a ninefold proportion, would make such stars appear like those of the seventh magnitude.

By following the same supposition, we may imagine stars of the seventh magnitude to be removed successively to four, five, six, &c. times their present distance, when their light would be decreased in a sixteen-fold, twenty-five-fold, and thirty-six-fold, &c. proportion, so that all would be removed far beyond the limits of visibility by the naked eye. But if telescopes be successively directed to such stars, which are capable of increasing the light received from them in a sixteen-fold, twenty-five-fold, thirty-six-fold, &c. proportion, they will be all seen as stars of the seventh magnitude.

Although it be highly probable, if not certain, that the innumerable suns, which appear to us as stars, have different real magnitudes, we may, in taking them in large collections, assume that their average magnitude is the same or nearly so, since it is in the highest degree improbable, that the small suns would be all placed at the greatest distances from the solar system, while the large suns would be placed nearest to it. Assuming, then, that the average magnitude of the stars taken in large collections is uniform, it will follow, that their succession of distances will be proportional to the square roots of the powers of the telescopes, which are capable of collecting sufficient light from them to give them the appearance of stars of a given magnitude, the seventh, for example, as seen with the naked eye.

39. Such was the principle which inspired Sir W. Herschel with the stupendous idea of gauging the universe. He contrived to vary the power of his telescopes to collect the light of the stars in such a manner as to bring into view, successively, those which filled regions of space between given limits of distance.

This is what has been called the *space-penetrating power* of the telescope.

If the light of a star of the sixth magnitude be 100 times less than that of a star of the first magnitude, a telescope which would augment the light 100 times, would exhibit it with the same apparent brightness as a star of the first magnitude.

Thus, for example, the reflecting telescope used by Sir William Herschel, in some of his principal stellar researches, had an aperture of eighteen inches, and twenty feet focal length, with a magnifying power of 180. The space-penetrating power of this instrument was found to be seventy-five, the meaning of which is, that when directed to a star of any given brightness, it would augment its brightness so as to make it appear the same as it would be if at seventy-five times less distance, or what is the same, that a star which to the naked eye would appear of the same brightness as that star does when seen in the telescope would require to be removed to seventy-five times the actual distance, so that when seen through the telescope it would have the brightness it has when seen with the naked eye. Thus a star of the sixth magnitude, if removed to seventy-five times the actual distance, would appear in such an instrument still as a star of the sixth magnitude would to the naked eye; and if we assume with Sir John Herschel, that a star of the sixth magnitude has a hundred times less light than α Centauri, and is therefore at ten times a greater distance, it will follow that α Centauri would require to be removed to 750 times its actual distance, so that when viewed through such telescope it would be seen as a star of the sixth magnitude is to the naked eye.

40. If, then, it be assumed, as it may fairly be, that among the innumerable stars which are beyond the range of unaided vision, and brought into view by the telescope, a large proportion must have the same magnitude and intrinsic brightness as the average stars of the first magnitude, it will follow that these must be at distances 750 times greater than the distance of an average star of the first magnitude, such as α Centauri. But it has been already shown that the distance of α Centauri is such that light would require 3·54217 years to come from it to the earth. It would therefore follow, that the distance of the telescopic stars just referred to, must be such that light would take to come from them to the earth

$$3{\cdot}54217 \times 750 = 2656{\cdot}6275 \text{ years.}$$

If it be desired to ascertain the distance of such stars, taking the earth's distance from the sun as the unit, we shall have

$$225920 \times 750 = 169{,}440000.$$

It appears, therefore, that the distance of such a star would be about one hundred and seventy million times the distance of the sun; and since the distance of the sun expressed in round numbers is one hundred millions of miles, it will follow that the distance of such a star is seventeen thousand billions of miles.

We arrive, therefore, at the somewhat astonishing conclusion that the distance of these objects, the existence of which the telescope alone has disclosed to us, must be such that light, moving at the rate of 192000 miles per second, takes upwards of 2600 years to come from them to us, and consequently that the objects we now see are not those which now exist, but those which did exist 2600 years ago; and it is within the scope of physical possibility that they may have changed their conditions of existence, and consequently of appearance, or even have ceased to exist altogether, more than 2000 years ago, although we actually see them at this moment.

This incidentally shows that the actual perception of a visible object is no conclusive evidence of its present existence. It is only a proof of its existence at some anterior period.

It appears, then, that there are numerous orders of stars, which by reason of their remoteness are invisible to the naked eye, but which are rendered visible by the telescope; and these stars are, like those visible to the naked eye, of an infinite variety of degrees of magnitude and brightness, and have accordingly been classed by astronomers according to an order of magnitudes in numerical continuation of that which has been somewhat indefinitely or arbitrarily adopted for the visible stars. Thus, supposing that the last order of stars visible without telescopic aid is the seventh, the first order disclosed by the telescope will be the eighth, and from these the telescopic stars, decreasing in magnitude, have been denominated the ninth, tenth, eleventh, &c. to the sixteenth, or seventeenth magnitude, the last being the smallest stars which are capable of being rendered distinctly visible by the most powerful telescope.

Besides bringing within the range of observation objects placed beyond the sphere which limits the play of natural vision, the telescope has greatly multiplied the number of objects visible within that sphere, by enabling us to see many rendered invisible by their minuteness, or confounded with others by their apparent proximity. Among the stars also which are visible to the naked eye, there are many, respecting which the telescope has disclosed circumstances of the highest physical interest, by which they have become more closely allied to our system, and by which it is demonstrated that the same material laws which coerce the planets, and give stability, uniformity, and harmony to their motions, are also in operation in the most remote regions of the universe.

We shall first notice some of the most remarkable discoveries respecting individual stars, and shall afterwards explain those which indicate the arrangement, dimensions, and form of the collective mass of stars which compose the visible firmament, and the results of those researches which the telescope has enabled astronomers to make in regions of space still more remote.

PERIODIC STARS.

41. The stars in general, as they are stationary in their apparent positions, are equally invariable in their apparent magnitudes and brightness. To this, however, there are several remarkable exceptions. Stars have been observed, sufficiently numerous to be regarded as a distinct class, which exhibit periodical changes of appearance. Some undergo gradual and alternate increase and diminution of magnitude, varying between determinate limits, and presenting these variations in equal intervals of time. Some are observed to attain a certain maximum magnitude, from which they gradually and regularly decline until they altogether disappear. After remaining for a certain time invisible, they re-appear and gradually increase till they attain their maximum splendour, and this succession of changes is regularly and periodically repeated. Such objects are called PERIODIC STARS.

42. The most remarkable of this class is the star called *Omikron*, in the neck of the Whale, which was first observed by David Fabricius, on the 13th August, 1596. This star retains its greatest brightness for about fourteen days, being then equal to a large star of the second magnitude. It then decreases continually for three months until it becomes invisible. It remains invisible for five months, when it re-appears, and increases gradually for three months until it recovers its maximum splendour. This is the general succession of its phases. Its entire period is about 332 days. This period is not always the same, and the gradations of brightness through which it passes are said to be subject to variation. Hevelius states that, in the interval between 1672 and 1676, it did not appear at all.

Some recent observations and researches of M. Argelander, render it probable that the period of this star is subject to a variation which is itself periodical, the period being alternately augmented and diminished to the extent of twenty-five days. The variations of the maximum lustre are also probably periodical.

The star called *Algol*, in the head of *Medusa*, in the constellation of *Perseus*, affords a striking example of the rapidity with which these periodical changes sometimes succeed each other. This star generally appears as one of the second magnitude; but an interval of seven hours occurs at the expiration of every sixty-two, during the first three hours and a half of which it gradually diminishes in brightness till it is reduced to a star of the fourth magnitude, and during the remainder of the interval it again gradually increases until it recovers its original magnitude. Thus, if we suppose it to have attained its maximum splendour at midnight on the first day of the month, its changes would be as follows:—

D.	H.	M.		D.	H.	M.	
0	0	0	to	2	14	0	It appears of second magnitude.
2	14	0	to	2	17	24	It decreases gradually to fourth magnitude.
2	17	24	to	2	20	48	It increases gradually to second magnitude.
2	20	48	to	5	10	48	It appears of second magnitude.
5	10	48	to	5	14	12	It decreases to fourth magnitude.
5	14	12	to	5	17	36	It increases to second magnitude.
			&c.				&c. &c.

This star presents an interesting example of its class, as it is constantly visible, and its period is so short that its succession of phases may be frequently and conveniently observed. It is situate near the foot of the constellation *Andromeda*, and lies a few degrees north-east of three stars of the fourth magnitude, which form a triangle.

Goodricke, who discovered the periodic phenomena of *Algol* in 1782, explained these appearances by the supposition that some opaque body revolves round it, being thus periodically interposed between the earth and the star, so as to intercept a large portion of its light.

The more recent observations on this star indicate a decrease of its period, which proceeds with accelerated rapidity. Sir J. Herschel thinks that this decrease will attain a limit, and will be followed by an increase, so that the variation of the period will prove itself to be periodic.

The stars δ in *Cepheus* and β in *Lyra* are remarkable for the regular periodicity of their lustre. The former passes from its least to its greatest lustre in thirty-eight hours, and from its greatest to its least in ninety-one hours. The changes of lustre of the latter, according to the recent observations of M. Argelander, are very complicated and curious. Its entire period is 12 days 21 hrs. 53 min. 10 sec., and in that time it first increases in lustre, then decreases, then increases again, and then decreases, so that it has two maxima and two minima. At the two maxima its lustre is that of a star of the 3·4 magnitude, and at one of the minima its lustre is that of a star of the 4·3, and at the other that of a star of the 4·5 magnitude. In this case also the period of the star is found to be periodically variable.

43. In the following Table the stars periodically variable, discovered up to 1848, are given, with their periods and extremes of lustre. This Table has been collected from various astronomical records by Sir J. Herschel.

PERIODIC STARS.

No.	Star.		Period.	Change of Magnitude.		Discovered by
			d. dec.	from	to	
1	β	Persei (Algol)	2·8673	2	4	Goodricke, 1782.
2	λ	Tauri	4±	4	5·4	Baxendell, 1848.
3	δ	Cephei	5·3664	3·4	5	Goodricke, 1784.
4	η	Aquilæ	7·1763	3·4	4·5	Pigott, 1784.
5	*	Cancri R.A. (1800)=8^h 32·5^m N.P.D. 70° 15′	9·015	7·8	10	Hind, 1848.
6	ζ	Geminorum	10·2	4·3	4·5	Schmidt, 1847.
7	β	Lyræ	12·9119	3·4	4·5	Goodricke, 1784.
8	α	Herculis	63±	3	4	Herschel, 1796.
9	59	B.Scuti R.A.(1801)=18^h 37^m N.P.D.=95° 57′	71·200	5	0	Pigott, 1795.
10	ε	Aurigæ	250±	3	4	Heis, 1846.
11	ο	Ceti (Mira)	331·63	2	0	Fabricius, 1596.
12	*	Serpentis R. A. (1828) =15^h 46^m 45^s; N.P. D. 74° 20′ 30″	335±	7 ?	0	Harding, 1826.
13	χ	Cygni	396·875	6	11	Kirch, 1687.
14	υ	Hydræ (B.A.C. 4501)	494±	4	10	Maraldi, 1704.
15	*	Cephei (B.A.C. 7582)	5 or 6 years	3	6	Herschel, 1782.
16	34	Cygni (B.A.C. 6990).	18 years ±	6	0	Janson, 1600.
17	*	Leonis (B.A.C. 3345)	Many years	6	0	Koch, 1782.
18	κ	Sagittarii	Ditto	3	6	Halley, 1676.
19	ψ	Leonis	Ditto	6	0	Montanari, 1667.
20	η	Cygni	Ditto	4·5	5·6	Herschel, Jun., 1842?
21	*	Virginis R. A. (1840)= 12^h 3^m N.P.D. 82° 8′	145 days	6·7	0	Harding, 1814.
22	*	Coronæ Bor. (B.A.C. 5236)	10½ months	6	0	Pigott, 1795.
23	7	Arietis (B.A.C. 581)	5 years ?	6	8	Piazzi, 1798.
24	η	Argûs	Irregular	1	4	Burchell, 1827.
25	α	Orionis	Irregular	1	1·2	Herschel, Jun., 1836.
26	α	Ursæ majoris	Some years	1·2	2	Ditto, 1846.
27	η	Ursæ majoris	Ditto	1·2	2	Ditto, 1846.
28	β	Ursæ minoris	2 or 3 years ?	2	2·3	Struve, 1838.
29	α	Cassiopeiæ	225 days ?	2	2·3	Herschel, Jun., 1838.
30	α	Hydræ	29 or 30 days ?	2·3	3	Ditto, 1837.
31	*	R. A. (1847)=22^h 58^m 57·9^s N. P. D.=80° 17′ 30″	Unknown	8 ?	0	Hind, 1848.
32	*	R. A. (1848) = 7^h 33^m 55·2^s N. P. D.=66° 11′ 56″	Ditto	9	0	Ditto, 1848.
33	*	R. A. (1848) = 7^h 40^m 10·3^s N. P. D. = 65° 53′ 29″	Ditto	9	0	Ditto, 1848.
34	Near *	R. A. 22^h 21^m 0·4^s (1848) N.P.D.=100° 42′ 40″	Ditto	7·8	0	Rümker.
35	*	R. A. (1848) 14^h 44^m 39·6^s N. P. D. 101° 45′ 25″	Ditto	8	9·10	Schumacher.
36	δ	Ursæ majoris	Many years	2 ?	2·3	Matter of general remark.

N.B. In the above list the letters B. A. C. indicate the catalogue of the British Association, B. the catalogue of Bode. Numbers before the name of the constellation (as 34 Cygni) denote Flamsteed's stars. Since this Table was drawn up, four additional stars, variable from the 8th or 9th magnitude to 0, have been communicated to us by Mr. Hind, whose places are as follow: (1.) R. A. $1^h\ 38^m\ 24^s$; N. P. D. 81° 9′ 39″; (2.) $4^h\ 50^m\ 42^s$, 80° 6′ 36″ (1846); (3.) $8^h\ 43^m\ 8^s$, 86° 11′ (1800); (4.) $22^h\ 12^m\ 9^s$, 82° 59′ 24″ (1800). Mr. Hind remarks that about several variable stars some degree of haziness is perceptible at their minimum. Have they clouds revolving round them as planetary or cometary attendants? He also draws attention to the fact that the red colour predominates among variable stars generally. The double star, No. 2718 of Struve's Catalogue, R. A. $20^h\ 34^m$ P. D. 77° 54′, is stated by Sir John Herschel to be variable. Captain Smyth (Celestial Cycle, i. 274) mentions also 3 Leonis and 18 Leonis as variable, the former from 6^m to 0, Period 78 days, the latter from 5^m to 10^m, Period $311^d\ 23^h$, but without citing any authority. Piazzi sets down 96 and 97 Virginis and 38 Herculis as variable stars.

In the case of many of the stars in the preceding Table, the variations of lustre are subject to considerable irregularities. Thus No. 13 was scarcely visible from 1698, for the interval of three years, even at the epochs when it ought to have had its greatest lustre. The extremes of lustre of No. 9 are also very variable and irregular. In general the variations of No. 22 are so inconsiderable as to be scarcely perceivable, but they become sometimes suddenly so great that the star wholly disappears. The variations of No. 25 were very conspicuous from 1836 to 1840, and again in 1849, being much less so in the intermediate time.

44. Several explanations have been proposed for these appearances.

1. Sir W. Herschel considered that the supposition of the existence of spots on the stars similar to the spots on the sun, combined with the rotation of the stars upon axes, similar to the rotation of the sun and planets, afforded so obvious and satisfactory an explanation of the phenomena, that no other need be sought.

2. Newton conjectured that the variation of brightness might be produced by comets falling into distant suns and causing temporary conflagrations. Waiving any other objection to this conjecture, it is put aside by its insufficiency to explain the periodicity of the phenomena.

3. Maupertius has suggested that some stars may have the form of thin flat disks, acquired either by extremely rapid rotation on an axis, or other physical cause. The ring of Saturn affords an example of this, within the limits of our own system, and the

modern discoveries in nebular astronomy offer other examples of a like form. The axis of rotation of such a body might be subject to periodical change like the nutation of the earth's axis, so that the flat side of the luminous disk might be presented more or less towards the earth at different times, and when the edge is so presented, it might be too thin to be visible. Such a succession of phenomena are actually exhibited in the case of the rings of Saturn, though proceeding from different causes.

4. Mr. Dunn * has conjectured that a dense atmosphere surrounding the stars, in different parts more or less pervious to light, may explain the phenomena. This conjecture, otherwise vague, indefinite, and improbable, totally fails to explain the periodicity of the phenomena.

5. It has been suggested that the periodical obscuration or total disappearance of the star, may arise from *transits* of the star by its attendant planets. The transits of Venus and Mercury are the basis of this conjecture.

The transits of none of the planets of the solar system, seen from the stars, could render the sun a periodic star. The magnitudes, even of the largest of them, are altogether insufficient for such an effect. To this objection it has been answered that planets of vastly greater comparative magnitude may revolve round other suns. But if the magnitude of a planet were sufficient to produce by its transit these considerable obscurations, it must be very little inferior to the magnitude of the sun itself, or at all events, it must bear a very considerable proportion to the magnitude of the sun; in which case it may be objected that the predominance of attraction necessary to maintain the sun in the centre of its system could not be secured. To this objection it is answered, that although the planet may have a great comparative *magnitude*, it may have a very small comparative *density*, and the gravitating attraction depending on the actual mass of matter, the predominance of the solar mass may be rendered consistent with the great relative magnitude of the planet by supposing the density of the one vastly greater than that of the other. The density of the sun is much greater than the density of Saturn.

6. It has been suggested that there may be systems in which the central body is a planet attended by a lesser sun revolving round it as the moon revolves round the earth, and in that case the periodical obscuration of the sun may be produced by its passage once in each revolution behind the central planet.

Such are the various conjectures which have been proposed to explain the periodic stars; and as they are merely conjectures,

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* Phil. Trans. vol. lii.

scarcely deserving the name of hypotheses or theories, we shall leave them to be taken for what they are worth.

TEMPORARY STARS.

Phenomena in most respects similar to those just described, but exhibiting no recurrence, repetition, or periodicity, have been observed in many stars. Thus, stars have from time to time appeared in various parts of the firmament, shone with extraordinary splendour for a limited time, and have then disappeared and have never again been observed.

45. The first star of this class which has been recorded, is one observed by *Hipparchus*, 125 B.C., the disappearance of which is said to have led that astronomer to make his celebrated catalogue of the fixed stars; a work which has proved in modern times of great value and interest. In the 389th year of our era, a star blazed forth near *α Aquilæ*, which shone for three weeks, appearing as splendid as the planet Venus, after which it disappeared and has never since been seen. In the years 945, 1264, and 1572, brilliant stars appeared between the constellations of *Cepheus* and *Cassiopeia*. The accounts of the positions of these objects are obscure and uncertain, but the intervals between the epochs of their appearances being nearly equal, it has been conjectured that they were successive returns of the same periodic star, the period of which is about 300 years, or possibly half that interval.

The appearance of the star of 1572 was very remarkable, and having been witnessed by the most eminent astronomers of that day, the account of it may be considered to be well entitled to confidence. Tycho Brahe, happening to be on his return on the evening of the 11th November from his laboratory to his dwelling-house, found a crowd of peasants gazing at a star which he was sure did not exist half an hour before. This was the temporary star of 1572, which was then as bright as the dog-star, and continued to increase in splendour until it surpassed Jupiter when that planet is most brilliant, and finally it attained such a lustre, that it was visible at mid-day. It began to diminish in December, and altogether disappeared in March, 1574.

On the 10th October, 1604, a splendid star suddenly burst out in the constellation of *Serpentarius*, which was as bright as that of 1572. It continued visible till October, 1605, when it vanished.

46. A star of the fifth magnitude, easily visible to the naked eye, was seen by Mr. Hind in the constellation of Ophiuchus, on the night of the 28th April, 1848. From the perfect acquaint-

ance of that observer with the region of the firmament in which he saw it, he was quite certain that, previous to the 5th April, no star brighter than those of the ninth magnitude had been there, nor is there any star in the catalogues at all corresponding to that which he saw there on the 28th. This star continued to be seen until the advance of the season and its low altitude rendered it impossible to be observed. It, however, constantly diminished in lustre until it disappeared, and has not since been seen.

47. To the class of temporary stars may be referred the cases of numerous stars which have disappeared from the firmament. On a careful examination of the heavens, and a comparison of the objects observed with former catalogues, and of catalogues ancient and modern with each other, many stars formerly known are now ascertained to be missing; and although, as Sir John Herschel observes, there is no doubt that in many instances these apparent losses have proceeded from mistaken entries, yet it is equally certain that in numerous cases there can have been no mistake in the observation or the entry, and that the star has really existed at a former epoch, and certainly has since disappeared.

When we consider the vast length of many of the periods of astronomical phenomena, it is far from being improbable that these phenomena, which seem to be occasional, accidental, and springing from the operation of no regular physical causes, such as those indicated by the class of variable stars first considered, may after all be periodic stars of the same kind, whose appearances and disappearances are brought about by similar causes. All that can be certainly known respecting them is, that they have appeared or disappeared once in that brief period of time within which astronomical observations have been made and recorded. If they be periodic stars, the length of whose period exceeds that interval, their changes could only have been once exhibited to us, and after ages have rolled away, and time has converted the future into the past, astronomers may witness the next occurrence of their phases, and discover that to be regular, harmonious, and periodic, which appears to us accidental, occasional, and anomalous.

DOUBLE STARS.

When the stars are examined individually by telescopes of a certain power, it is found that many which to the naked eye appear to be single stars, are in reality two stars placed so close together that they appear as one. These are called *double stars.*

48. A very limited number of these objects had been discovered

before the telescope had received the vast accession of power which was given to it by the labour and genius of Sir William Herschel. That astronomer observed and catalogued 500 double stars; and subsequent observers, among whom his son, Sir John Herschel, holds the foremost place, have augmented the number to 6000.

49. The close apparent juxta-position of two stars in the firmament is a phenomenon which might be easily explained, and which could create no surprise. Such an appearance would be produced by the accidental circumstance of the lines of direction of the two stars as seen from the earth, forming a very small angle, in which case, although the two stars might in reality be as far removed from each other as any stars in the heavens, they would nevertheless *appear* close together. The fig. 5 will render this easily understood. Let *a* and *b* be the two stars seen from *c*. The star *a* will be seen relatively to *b*, as if it were at *d*, and the two objects will seem to be in close juxta-position; and if the angle under the lines *c a* and *c b* be less than the sum of the apparent semi-diameters of the stars, they would actually appear to touch.

Fig. 5.

50. If such objects were few in number, this mode of explaining them might be admitted; and such may, in fact, be the cause of the phenomenon in some instances. The chances against such proximity of the lines of direction are however so great as to be utterly incompatible with the vast number of double stars that have been discovered, even were there not, as there is, other conclusive proof that this proximity and companionship is neither accidental nor merely apparent, but that the connection is real, and that the objects are united by a physical bond analogous to that which attaches the planets to the sun.

But apart from the proofs of real proximity which exist respecting many of the double stars, and which will presently be explained, it has been shown that the probability against mere optical juxta-position such as that described above is almost infinite. Professor Struve has shown that, taking the number of stars whose existence has been ascertained by observation down to the 7th magnitude inclusive, and supposing them to be scattered fortuitously over the entire firmament, the chances against any two of them having a position so close to each other as 4″ would be 9570 to 1. But when this calculation was made, considerably more than 100 cases of such duple juxta-position were ascertained to exist. The same astronomer also calculated that the chances against a third star falling within 32″ of the first two would be 173524 to 1; yet the firmament presents at least four such triple combinations.

Among the most striking examples of double stars may be mentioned the bright star *Castor*, which, when sufficiently magnified, is proved to consist of two stars between the third and fourth magnitudes, within five seconds of each other. There are many, however, which are separated by intervals less than one second; such as ε *Arietis*, *Atlas Pleiadum*, γ *Coronæ*, η and ζ *Herculis*, and τ and λ *Ophiuchi*.

51. Another argument against the supposition of mere fortuitous optical juxta-position, unattended by any physical connection, is derived from a circumstance which will be fully explained hereafter. Certain stars have been ascertained to have a *proper motion*, that is, a motion exclusively belonging to each individual star, in which the stars around it do not participate. Now, some of the double stars have such a motion. If one individual of the pair were affected by a proper motion, in which the other does not participate, their separation at some subsequent epoch would become inevitable, since one would necessarily move away from the other. Now, no such separation has in any instance been witnessed. It follows, therefore, that the proper motion of one equally affects the other, and consequently, that their juxta-position is real and not merely optical.

52. The systematic observation of double stars, and their reduction to a catalogue with individual descriptions, commenced by Sir W. Herschel, has been continued with great activity and success by Sir J. Herschel, Sir J. South, and Professor Struve, so that the number of these objects now known, as to character and position, amounts to several thousand, the individuals of each pair being less than 32″ asunder. They have been classed by Professor Struve according to their distances asunder, the first class being separated by a distance not exceeding 1″, the second between 1″ and 2″, the third between 2″ and 4″, the fourth between 4″ and 8″, the fifth between 8″ and 12″, the sixth between 12″ and 16″, the seventh between 16″ and 24″, and the eighth between 24″ and 32″.

53. The double stars in the following table have been selected

by Sir J. Herschel from Struve's catalogue, as remarkable examples of each class well adapted for observation by amateurs, who may be disposed to try by them the efficiency of telescopes.

0″ to 1″.	1″ to 2″.	2″ to 4″.	4″ to 8″.
γ Coronæ Bor.	γ Circini.	α Piscium.	α Crucis.
γ Centauri.	δ Cygni.	β Hydræ.	α Herculis.
γ Lupi.	ε Chamaleontis.	γ Ceti.	α Gemin.
ε Arietis.	ζ Bootis.	γ Leonis.	δ Gemin.
ζ Herculis.	ι Cassiopeiæ.	γ Cor. Aus.	ζ Cor. Bor.
η Coronæ.	ι 2 Cancri.	γ Virginis.	θ Phænicis.
η Herculis.	ξ Ursæ maj.	δ Serpentis.	κ Cephei.
λ Cassiopeiæ.	π Aquilæ.	ε Bootis.	λ Orionis.
λ Ophiuchi.	σ Coro. Bor.	ε Draconis.	μ Cygni.
π Lupi.	2 Camelopar.	ε Hydræ.	ξ Bootis.
η Ophiuchi.	32 Orionis.	ζ Aquarii.	ξ Cephei.
φ Draconis.	52 Orionis.	ζ Orionis.	π Bootis.
φ Ursæ maj.		ι Leonis.	ρ Capricor.
χ Aquilæ.		ι Trianguli.	ν Argus.
ω Leonis.		κ Leporis.	ω Aurigæ.
Atlas Pleiad.		μ Draconis.	μ Eridani.
4 Aquarii.		μ Canis.	70 Ophiuchi.
42 Comæ.		ρ Herculis.	12 Eridani.
52 Arietis.		σ Cassiopeiæ.	32 Eridani.
66 Piscium.		44 Bootis.	44 Herculis.

8″ to 12″.	12″ to 16″.	16″ to 24″.	21″ to 32″.
β Orionis.	α Centauri.	α Can. Ven.	δ Herculis.
γ Arietis.	β Cephei.	ε Normæ.	η Lyræ.
γ Delphini.	β Scorpii.	ζ Piscium.	ι Cancri.
ζ Antliæ Pn.	γ Volantis.	θ Serpentis.	κ Herculis.
η Cassiopeiæ.	η Lupi.	κ Cor. Aus.	κ Cephei.
θ Eridani.	ζ Ursa maj.	κ Tauri.	ψ Draconis.
ι Orionis.	κ Bootis.	24 Comæ.	κ Cygni.
f Eridani.	8 Monocerotis.	41 Draconis.	23 Orionis.
2 Can. Ven.	61 Cygni.	61 Ophiuchi.	

54. One of the characters observed among the double stars is the frequent occurrence of stars of different colours found together. Sometimes these colours are complementary; and when this occurs, it is possible that the fainter of the two may be a white star, which appears to have the colour complementary to that of the more brilliant, in consequence of a well-understood law of vision, by which the retina being highly excited by light of a particular colour is rendered insensible to less intense light of the same

colour, so that the complement of the whole light of the fainter star finds the retina more sensible than that part which is identical in colour with the brighter star, and the impression of the complementary colour accordingly prevails. In many cases, however, the difference of colour of the two stars is real.

When the colours are complementary, the more brilliant star is generally of a bright red or orange colour, the smaller appearing blueish or greenish. The double stars ι Cancri and γ Andromachæ are examples of this. According to Sir J. Herschel, insulated stars of a red colour, some almost blood-red, occur in many parts of the heavens; but no example has been met with of a decidedly green or blue star unassociated with a much brighter companion.

55. When telescopes of the greatest efficiency are directed upon some stars, which to more ordinary instruments appear only double, they prove to consist of three or more stars. In some cases one of the two companions only is double, so that the entire combination is triple. In others, both are double, the whole being, therefore, a quadruple star. An example of this latter class is presented by the star ε Lyræ. Sometimes the third star is much smaller than the principal ones, for example, in the cases of ζ Cancri, ξ Scorpii, 11 Monocerotis, and 12 Lyncis. In others, as in θ Orionis, the four component stars are all conspicuous.

56. When the attention of astronomers was first attracted to double stars, it was thought they would afford a most promising means of determining the annual parallax, and thereby discovering the distance of the stars. If we suppose the two individuals composing a double star, being situate very nearly in the same direction as seen from the earth, to be at very different distances, it might be expected that their apparent relative position would vary at different seasons of the year, by reason of the change of position of the earth.

Let A and B, fig. 6, represent the two individuals composing a double star. Let C and D represent two positions of the earth in its annual orbit, separated by an interval of half a year, and placed therefore on opposite sides of the sun S. When viewed from C, the star B will be to the left of the star A; and when viewed from D, it will be to the right of it. During the intermediate six months the relative change of position would gradually be effected, and the one star would thus appear either to revolve annually round the other, or would oscillate semi-annually from side to side of the other. The extent of its play compared with the diameter C D of the earth's orbit, would supply the data necessary to determine the proportion which the distance of the stars would bear to that diameter.

The great problem of the stellar parallax seemed thus to be

Fig. 6.

reduced to the measurement of the small interval between the individuals of double stars; and it happened fortunately, that the micrometers used in astronomical instruments were capable of measuring these minute angles with much greater relative accuracy than could be attained in the observations on greater angular distances. To these advantages were added the absence of all possible errors arising from refraction, errors incidental to the graduation of instruments, from uncertainty of levels and plumb-lines, from all estimations of aberration and precession; in a word from all effects which, equally affecting both the individual stars observed, could not interfere with the results of the observations, whatever they might be.

57. These considerations raised great hopes among astronomers, that the means were in their hands to resolve finally the great problem of the stellar parallax, and Sir William Herschel accordingly engaged, with all his characteristic ardour and sagacity, in an extensive series of observations on the numerous double stars, for the original discovery of which science was already so deeply indebted to his labours. He had not, however, proceeded far in his researches, when phenomena unfolded themselves before him, indicating a discovery of a much higher order and interest than that of the parallax which he sought. He found that the relative position of the individuals of many of the double stars which he examined were subject to a change, but that the period of this change had no relation to the period of the earth's motion. It is evident that whatever appearances can proceed from the earth's annual motion, must be not only periodic and regular, but must pass annually through the same series of phases, always showing the same phase on each return of the same epoch of the sidereal year. In the changes of position which Sir William Herschel observed in the double stars, no such series of phases presented themselves. Periods, it is true, were soon developed; but these periods were regulated by intervals which neither agreed with each other nor with the earth's annual motion.

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Page	43,	line	8,	*for*	"February"	*read*	"April."
,,	159,	,,	29,	,,	"December"	,,	"June."
,,	,,	,,	32,	,,	"June"	,,	"December."
,,	,,	,,	35,	,,	"summer"	,,	"winter."
,,	,,	,,	36,	,,	"latter"	,,	"early."
,,	162,	,,	23,	,,	"June"	,,	"December."
,,	170,	,,	1,	,,	"seven"	,,	"eight."

Fig. 56.*
OVAL BLUISH NEBULA, OBSERVED BY SIR JOHN HERSCHEL.

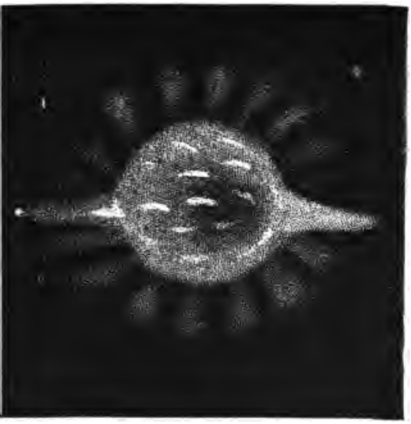

Fig. 57.*
THE SAME OBJECT, AS SHOWN BY THE GREAT ROSSE TELESCOPE.

THE STELLAR UNIVERSE.

CHAPTER IV.

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58. SOME other explanation of the phenomena must, therefore, be sought for; and the illustrious observer soon arrived at the conclusion; that these apparent changes of position were due to real motions in the stars themselves; that these stars, in fact, moved in proper orbits in the same manner as the planets moved around the sun. The slowness of the succession of changes which

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* See note, p. 193, vol. vii.

were observed, rendered it necessary to watch their progress for a long period of time before their motions could be certainly or accurately known; and accordingly, although these researches were commenced in 1778, it was not until the year 1803 that the observer had collected data sufficient to justify any positive conclusion respecting their orbital motions. In that and the following year, Sir William Herschel announced to the Royal Society, in two memorable papers read before that body, that there exist sidereal systems consisting of two stars revolving about each other in regular orbits, and constituting what he called *binary stars*, to distinguish them from double stars, generally so called, in which no such periodic change of position is discoverable. Both the individuals of a binary star are at the same distance from the eye in the same sense in which the planet Uranus and its attendant satellites are said to be at the same distance.

More recent observation has fully confirmed these remarkable discoveries. In 1841, Mädler published a catalogue of upwards of 100 stars of this class, and every year augments their number. These stars require the best telescopes for their observation, being generally so close as to render the use of very high magnifying powers indispensable.

59. The moment the revolution of one star round another was ascertained, the idea of the possible extension of the great principle of gravitation to these remote regions of the universe naturally suggested itself. Newton has proved in his *Principia*, that if a body revolve in an ellipse by an attractive force directed to the focus, that force will vary according to the law which characterises gravitation. Thus an elliptical orbit became a *test* of the presence and sway of the law of gravitation. If, then, it could be ascertained that the orbits of the double stars were ellipses, we should at once arrive at the fact that the law of which the discovery conferred such celebrity on the name of Newton, is not confined to the solar system, but prevails throughout the universe.

60. The first distinct system of calculation by which the true elliptic elements of the orbit of a binary star were ascertained, was supplied in 1830, by M. Savary, who showed that the motion of one of the most remarkable of these stars (ξ *Ursæ majoris*), indicated an elliptic orbit described in 58¼ years. Professor Encké, by another process, arrived at the fact that the star 60 *Ophiuchi* moved in an ellipse with a period of 74 years. Several other orbits were ascertained and computed by Sir John Herschel, MM. Mädler, Hind, Smyth, and others.

61. The following Table is given by Sir J. Herschel, as containing the principal results of observation in this part of stellar astronomy up to 1850.

BINARY STARS.

Star's Name.	Apparent semi-axis.	Excentricity.	Position of Node.	Perihelion from Node or Orbit.	Inclination.	Period in Years.	Perihelion Passage.	By whom computed.
1. Herculis	1·189″	0·44454	39° 26′	262° 4′	50° 53′	31·468	1829·50	Mädler.
2. η Coronæ B.	1·088	0·33760	24 18	261 21	71 8	43·246	1815·23	Ditto.
3. ζ Cancri	1·292	0·23486	1 28	266 0	63 17	58·910	1853·37	Ditto.
4. a. ξ Ursæ majoris	3·857	0·41640	95 22	131 38	50 40	58·262	1817·25	Savary.
4. b. Ditto	3·278	0·37770	97 47	134 22	56 6	60·720	1816·73	Herschel, junior.
4. c. Ditto	2·417	0·41350	98 52	130 48	54 56	61·464	1816·44	Mädler.
5. ω Leonis	0·857	0·64338	135 11	185 27	46 33	82·533	1849·76	Ditto.
6. a. p. Ophiuchi	4·328	0·43007	147 12	125 22	46 25	73·862	1806·88	Encké.
6. b. Ditto	4·392	0·46670	137 2	145 46	48 5	80·340	1807·06	Herschel, junior.
6. c. Ditto	4·192	0·44380	126 55	142 53	64 51	92·870	1812·73	Mädler.
7. Σ 3062	1·255	0·44958	15 3	137 27	35 31	94·765	1837·41	Ditto.
8. ξ Bootis	12·560	0·59374	359 59	100 59	80 5	117·140	1779·88	Herschel, junior.
9. δ Cygni	1·811	0·60667	24 54	243 24	46 23	178·700	1862·87	Hind.
10. γ Virginis	3·580	0·87952	5 33	313 45	23 36	182·120	1836·43	Herschel, junior.
11. a. Castor	8·086	0·75820	58 6	97 29	70 3	252·660	1855·83	Ditto.
11. b. Ditto	7·008	0·79725	23 5	87 37	70 58	232·124	1913·90	Mädler.
11. c. Ditto	6·300	0·24050	11 24	356 22	43 14	632·270	1699·26	Hind.
12. a. σ Coronæ B.	3·918	0·69978	25 7	64 38	29 29	608·450	1826·60	Mädler.
12. b. Ditto	5·194	0·72560	21 3	69 24	25 39	736·880	1826·48	Hind.
13. μ 2 Bootis	3·218	0·84010	117 21	103 17	46 57	649·720	1852·50	Ditto.
14. α Centauri	15·500	0·95000	86 7	291 22	47 56	77·000	1851·50	Jacob.

The elements Nos. 1, 2, 3, 4 c, 5, 6 c, 7, 11 b, 12 a, are extracted from M. Mädler's synoptic view of the history of double stars, in vol. ix. of the Dorpat Observations: 4 a, from the Connoiss. des Temps, 1830: 4 b, 6 b, and 11 a, from vol. v. Trans. Astron. Soc. Lond.: 6 a, from Berlin Ephemeris, 1832: No. 8. from Trans. Astron. Soc. vol. vi.: No. 9, 11 c, 12 b, and 13 from Notices of the Astronomical Society, vol. vii. p. 22., and viii. p. 159., and No. 10 from Sir John Herschel's "Results of Astronomical Observations, &c., at the Cape of Good Hope," p. 297. The Σ prefixed to No. 7 denotes the number of the star in M. Struve's Dorpat Catalogue (Catalogus Novus Stellarum Duplicium, &c., Dorpat. 1827), which contains the places for 1826 of 3112 of these objects.

The "position of the node" in col. 4, expresses the angle of position of the line of intersection of the plane of the orbit, with the plane of the heavens on which it is seen projected. The "inclination" in col. 6, is the inclination of these two planes to one another. Col. 5, shows the angle actually included *in the plane of the orbit*, between the line of nodes (defined as above) and the line of apsides. The elements assigned in this table to ω Leonis, ξ Bootis, and Castor must be considered as very doubtful, and the same may perhaps be said of those ascribed to μ 2 Bootis, which rest on too small an arc of the orbit, and that too imperfectly observed, to afford a secure basis of calculation.

62. The most remarkable of these, according to Sir John Herschel, is γ *Virginis;* not only on account of the length of its period, but by reason also of the great diminution of apparent distance and rapid increase of angular motion about each other, of the individuals composing it. It is a bright star of the fourth magnitude, and its component stars are almost exactly equal. It has been known to consist of two stars since the beginning of the eighteenth century, their distance being then between six and seven seconds; so that any tolerably good telescope would resolve it. Since that time they have been constantly approaching, and are at present hardly more than a single second asunder; so that no telescope that is not of very superior quality, is competent to show them otherwise than as a single star somewhat lengthened in one direction. It fortunately happens that Bradley, in 1718, noticed and recorded, in the margin of one of his observation-books, the apparent direction of their line of junction as being parallel to that of two remarkable stars α and δ of the same constellation, as seen by the naked eye. They are entered also as distinct stars in Mayer's catalogue; and this affords also another means of recovering their relative situation at the date of his observations, which were made about the year 1756. Without particularising individual measurements, which will be found in their proper repositories, it will suffice to remark, that their whole series is represented by an ellipse.

63. To understand the curious effects which must attend the case of a lesser sun with its attendant planets revolving round a

greater, let the larger sun with its planets be represented at S, fig. 7, in the focus of an ellipse, in which the lesser sun accompanied by *its* planets moves. At A this latter sun is in its perihelion, and nearest to the greater sun S. Moving in its periodical course to B, it is at its mean distance from the sun S. At D it is at aphelion, or its most distant point, and finally returns through C to its perihelion A. The sun S, because of its vast distance from the system A, would appear to the inhabitants of the planets of the system A much smaller than their proper sun; but, on the other hand, this effect of distance would be to a certain extent compensated by its greatly superior magnitude; for analogy justifies the inference that the sun S is greater than the sun A in a proportion equal to that of the magnitude of our sun to one of the planets. The inhabitants of the planets of the system A will then behold the spectacle of *two suns* in their firmament. The annual motion of one of these suns will be determined by the motion of the planet itself in its orbit, but that of the other and more distant sun will be determined by the period of the lesser sun around the greater in the orbit A B D C. The rotation of the planets on their axes will produce two days of equal length, but not commencing or ending simultaneously. There will be in general *two sunrises* and *two sunsets!* When a planet is situate in the part of its orbit between the two suns, there will be no night. The two suns will then be placed exactly as our sun and moon are placed when the moon is full. When the one sun sets, the other will rise; and when the one rises the other will set. There will be, therefore, continual day. On the other hand, when a planet is at such a part of its orbit that both suns lie in nearly the same direction as seen from it, both suns will rise and both will set together. There

Fig. 7.

will then be the ordinary alternation of day and night as on the earth, but the day will have more than the usual splendour, being enlightened by two suns.

In all intermediate seasons the two suns will rise and set at different times. During a part of the day both will be seen at once in the heavens, occupying different places, and reaching the meridian at different times. There will be *two noons*. In the morning for some time, more or less, according to the season of the year, one sun only will be apparent, and in like manner, in the evening, the sun which first rose will be the first to set, leaving the dominion of the heavens to its splendid companion.

The diurnal and annual phenomena incidental to the planets attending the central sun s will not be materially different, except that to them the two suns will have extremely different magnitudes, and will afford proportionally different degrees of light. The lesser sun will appear much smaller, both on account of its really inferior magnitude and its vastly greater distance. The two days, therefore, when they occur, will be of very different splendour, one being probably as much brighter than the other as the light of noonday is to that of full moonlight, or to that of the morning or evening twilight.

But these singular vicissitudes of light will become still more striking, when the two suns diffuse light of different colours. Let us examine the very common case of the combination of a *crimson* with a *blue* sun. In general, they will rise at different times. When the blue rises, it will for a time preside alone in the heavens, diffusing a blue morning. Its crimson companion, however, soon appearing, the lights of both being blended, a white day will follow. As evening approaches, and the two orbs descend toward the western horizon, the blue sun will first set, leaving the crimson one alone in the heavens. Thus a ruddy evening closes this curious succession of varying lights. As the year rolls on, these changes will be varied in every conceivable manner. At those seasons when the suns are on opposite sides of a planet, crimson and blue days will alternate, without any intervening night; and at the intermediate epochs all the various intervals of rising and setting of the two suns will be exhibited.

PROPER MOTION OF THE STARS.

In common parlance the stars are said to be *fixed*. They have received this epithet to distinguish them from the planets, the sun, and the moon, all of which constantly undergo changes of apparent position on the surface of the heavens. The stars, on the contrary, so far as the powers of the eye unaided by art can discover, never change their relative position in the firmament, which seems to be carried round us by the diurnal motion of the sphere, just as if the stars were attached to it, and merely shared in its apparent motion.

But the stars, though subject to no motion perceptible to the naked eye, are not absolutely fixed. When the place of a star on the heavens is exactly observed by means of good astronomical instruments, it is found to be subject to a change from month to month and from year to year, small indeed, but still easily observed and certainly ascertained.

64. It has been demonstrated by Laplace, that a system of bodies, such as the solar system, placed in space and submitted to no other continued force except the reciprocal attractions of the bodies which compose it, must either have its common centre of gravity stationary or in a state of uniform rectilinear motion.

The chances against the conditions which would render the sun stationary, compared with those which would give it a motion in *some* direction with *some* velocity, are so numerous, that we may pronounce it to be morally certain that our system is in motion in some determinate direction through the universe. Now, if we suppose the sun attended by the planets to be thus moved through space in any direction, an observer placed on the earth would see the effects of such a motion, as a spectator in a steamboat moving on a river would perceive his progressive motion on the stream by an apparent motion of the banks in a contrary direction. The observer on the earth would, therefore, detect such a motion of the solar system through space by the apparent motion in the contrary direction with which the stars would be affected.

65. Such a motion of the solar system would affect different stars differently. All would, it is true, appear to be affected by a contrary motion, but all would not be equally affected. The nearest would appear to have the most perceptible motion, the more remote would be affected in a less degree, and some might, from their extreme distance, be so slightly affected as not to exhibit any apparent change of place, even when examined with the most delicate instruments. To whatever degree each star might be affected, all the changes of position would, however, apparently take place in the same direction.

The apparent effects would also be exhibited in another manner. The stars in that region of the universe toward which the motion of the system is directed, would appear to recede from each other. The spaces which separate them would seem to be gradually augmented, while, on the contrary, the stars in the opposite quarter would seem to be crowded more closely together, the distances between star and star being gradually diminished. This will be more clearly comprehended by fig. 8.

Let the line s s′ represent the direction of the motion of the system, and let s and s′ represent its positions at any two epochs. At s, the stars A B C would be separated by intervals measured

Fig. 8.

by the angles A S B, and B S C, while at s′ they would appear separated by the lesser angles A S′ B, and B S′ C. Seen from s′, the stars A B C would seem to be closer together than they were when seen from s. For like reasons, the stars *a b c*, towards which the system is here supposed to move, would seem to be closer together when seen from s, than when seen from s′. Thus, in the quarter of the heavens towards which the system is moving, the stars might be expected to separate gradually, while in the opposite quarter they would become more condensed. In all the intermediate parts of the heavens they would be affected by a motion contrary to that of the solar system. Such, in general, would be the effects of a progressive motion of our system.

66. Although no general effect of this kind has been manifested in any conspicuous manner among the fixed stars, many of these objects have been found, in long periods of time, to have shifted their position in a very sensible degree. Thus, for example, the three stars, Sirius, Arcturus, and Aldebaran, have undergone, since the time of Hipparchus (130 B.C), a change of position southwards, amounting to considerably more than half a degree. The double star 61 Cygni has, in half a century, moved through nearly 4·3′, the two stars composing it being carried along in parallel lines with a common velocity. The stars ε Indi and μ Cassiopeiæ move at the rate of 7·74″ and 3·74″ annually.

Various attempts have been made to render these and other like changes of apparent position of the fixed stars compatible with some assumed motion of the sun. Sir W. Herschel, in 1783, reasoning upon the proper motions which had then been observed, arrived at the conclusion, that such appearances might be explained by supposing that the sun has a motion directed to a point near the star λ Herculis. About the same time, Prevost came to a like conclusion, assigning, however, the direction of the supposed motion to a point differing by 27° from that indicated by Sir W. Herschel.

Since that epoch, the proper motions of the stars have been more extensively and accurately observed, and calculations of the motions of the sun which they indicate, have been made by several astronomers. The following points have been assigned as the direction of the solar motion in 1790:—

R. A.	N. P. D.	
260° 34′	63° 43′	Sir W. Herschel.
256° 25′	51° 23′	Argelander.
255° 10′	51° 26′	,,
261° 11′	59° 2′	,,
252° 53′	75° 34′	Luhndahl.
261° 22′	62° 24′	Otto Struve.

The first estimate of Argelander was made from the proper motions of 21 stars, each of which has an annual motion greater than 1″; the second from 50 stars having annual proper motions between 1″ and 0·5″, and the third from those of 319 stars having motions between 0·5″ and 0·1″. The estimate of M. Luhndahl is based on the motions of 147 stars, and that of M. Struve on 392 stars.

The mean of all these estimates * is a point whose right ascension is 259° 9′, and north polar distance 55° 23′, which it will be seen differs very little from the point originally assigned by Sir W. Herschel.

All the preceding calculations being based on observations made on stars in the northern hemisphere, it was obviously desirable that similar estimates should be made from the observed proper motions of southern stars. Mr. Galloway undertook and executed these calculations; and found that the southern stars gave the direction of the solar motion for 1790, to be towards a point whose right ascension is 260° 1′, and north polar distance 55° 37′.

No doubt, therefore, can remain that the proper motion of the stars is produced by a real motion of the solar system, and that the direction of this motion in 1790 was towards a point of space which seen from the then position of the system had the right ascension of about 260°, and the north polar distance of about 55°.

67. It follows from these calculations, that the average displacement of the stars requires that the motion of the sun should be such as that if its direction were at right angles to a visual ray, drawn from a star of the first magnitude of average distance, its apparent annual motion would be 0·3392″; and taking the average parallax of such a star at 0·209″, if D express the semi-axis of the earth's orbit, the annual motion of the sun would be

$$\frac{3392}{2090} \times \text{D} = 1\cdot623\ \text{D}.$$

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* Herschel, Ast., 2nd Ed., p. 583.

It follows therefore, that the annual motion of the sun would be

$$1{\cdot}623 \times 95{,}000000 = 154{,}200000 \text{ miles};$$

and the daily motion

$$\frac{154{,}200000}{365\frac{1}{4}} = 422000 \text{ miles};$$

a velocity equal to something more than the fourth of the earth's orbital motion.

68. The motion of the sun, which has been computed in what precedes, is that which it had at a particular epoch. No account is taken of the possible or probable changes of direction of such motion. To suppose that the solar system should move continuously in one and the same direction, would be equivalent to the supposition that no body or collection of bodies in the universe would exercise any attraction upon it. It is obviously more consistent with probability and analogy, that the motion of the system is *orbital*, that is to say, that it revolves round some remote centre of attraction, and that the direction of its motion must continually change, although such change, owing to the great magnitude of its orbit, and the relative slowness of its motion, be so very slow as to be quite imperceptible within even the longest interval over which astronomical records extend.

Attempts have, nevertheless, been made to determine the centre of the solar motion; and Dr. Mädler has thrown out a surmise that it lies at a point in or near the small constellation of the Pleiades.

This and like speculations must, however, be regarded as conjectural for the present.

THE FORM AND DIMENSIONS OF THE MASS OF STARS WHICH COMPOSE THE VISIBLE FIRMAMENT.

69. The aspect of the firmament might, at first, impress the mind of an observer with the idea that the numerous stars scattered over it are destitute of any law or regularity of arrangement, and that their distribution is like the fortuitous position which objects casually flung upon such a surface might be imagined to assume. If, however, the different regions of the heavens be more carefully examined and compared, this first impression will be corrected, and it will, on the contrary, be found that the distribution of the stars over the surface of the celestial sphere follows a distinct and well defined law; that their density, or the number of them which is found in a given space of the heavens, varies regularly, increasing continually in certain directions and decreasing in others.

Sir W. Herschel submitted the heavens, or at least that part of them which is observable in these latitudes, to a rigorous telescopic survey, counting the number of individual stars visible in the field of view of a telescope of given aperture, focal length, and magnifying power, when directed to different parts of the firmament. The result of this survey proved that, around two points of the celestial sphere diametrically opposed to each other, the stars are more thinly scattered than elsewhere; that departing from these points in any direction, the number of stars included in the field of view of the same telescope increases first slowly, but at greater distances more rapidly; that this increase continues until the telescope receives a direction at right angles to the diameter which joins the two opposite points where the distribution is most sparse; and that in this direction the stars are so closely crowded together that it becomes, in some cases, impracticable to count them.

70. The two opposite points of the celestial sphere, around which the stars are observed to be most sparse, have been called the GALACTIC POLES; and the great circle at right angles to the diameter joining these points, has been denominated the GALACTIC CIRCLE.

This circle intersects the celestial equator at two points, situate 10° east of the equinoctial points, and is inclined to the equator at an angle of 63°, and, therefore, to the ecliptic at an angle of 40°.

In referring to and explaining the distribution of the stars over the celestial sphere, it will be convenient to refer them to this circle and its poles, as, for other purposes, they have been referred to the equator and its poles. We shall, therefore, express the distance of different points of the firmament from the galactic circle, in either hemisphere, by the terms north or south GALACTIC LATITUDE.

71. The elaborate series of stellar observations in the northern hemisphere made during a great part of his life, by Sir W. Herschel, and subsequently extended and continued in the southern hemisphere by Sir J. Herschel, has supplied data by which the law of the distribution of the stars, according to their galactic latitude, has been ascertained at least with a near approximation.

The great celestial survey executed by these eminent observers, was conducted upon the principle explained above. The telescope used for the purpose had 18 inches aperture, 20 feet focal length, and a magnifying power of 180. It was directed indiscriminately to every point of the celestial sphere visible in the latitude of the places of observation.

It was by means of a vast number of distinct observations thus made, that the position of the galactic poles was ascertained. The density of the stars, measured by the number included in each "gauge" (as the field of view was called), was nearly the same for the same galactic latitude, and increased in proceeding from the galactic pole, very slowly at first, but with great rapidity when the galactic latitude was much diminished.

72. An analysis of the observations of Sir W. Herschel, in the northern hemisphere, was made by Professor Struve, with the view of determining the mean density of the stars in successive zones of galactic latitude; and a like analysis has been made of the observations of Sir J. Herschel, in the southern hemisphere.

If we imagine the celestial sphere resolved into a succession of zones, each measuring 15° in breadth, and bounded by parallels to the galactic circle, the average number of stars included within a circle, whose diameter is 15′, and whose magnitude, therefore, would be about the fourth part of that of the disc of the sun or moon, will be that which is given in the second column of the following Table.

Galactic Latitude.	Average number of Stars in a circle 15′ diameter.
N 90° — 75°	4·32
,, 75° — 60°	5·42
,, 60° — 45°	8·21
,, 45° — 30°	13·61
,, 30° — 15°	24·09
,, 15° — 0°	53·43
S 0° — 15°	52·06
,, 15° — 30°	26·29
,, 30° — 45°	13·49
,, 45° — 60°	9·08
,, 60° — 75°	6·62
,, 75° — 90°	6·05

It appears, therefore, that the variation of the density of the visible stars in proceeding from the galactic plane, either north or south, is subject almost exactly to the same law of decrease, the density, however, at each latitude being somewhat greater in the southern than in the northern hemisphere.

73. The regions of the heavens, which extend to a certain distance on one side and the other of the galactic plane, are generally so densely covered with small stars, as to present to the naked eye the appearance, not of stars crowded together, but of whitish nebulous light. This appearance extends over a vast extent of the celestial sphere, deviating in some places from the exact direction of the galactic circle, bifurcating and diverging into two branches at a certain point which afterwards reunite, and at other places throwing out off-shoots. This appearance was denominated the *Via Lactea*, or the *galaxy*,* by the ancients, and it has retained that name.

The course of the milky way may be so much more easily and clearly

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* From the Greek word γάλα, γάλακτος, "milk."

followed by means of a map of the stars, or a celestial globe, upon which it is delineated, that it will be needless here to describe it.

74. When this nebulous whiteness is submitted to telescopic examination with instruments of adequate power, it proves to be a mass of countless numbers of stars, so small as to be individually undistinguishable, and so crowded together as to give to the place they occupy the whitish appearance from which the milky way takes its name.

Some idea may be formed of the enormous number of stars which are crowded together in those parts of the heavens, by the actual numbers so distinctly visible as to admit of being counted or estimated, which are stated by Sir W. Herschel to have been seen in spaces of given extent. He states, for example, that in those parts of the milky way in which the stars were most thinly scattered, he sometimes saw eighty stars in each field. In an hour, fifteen degrees of the firmament were carried before his telescope, showing successively sixty distinct fields. Allowing eighty stars for each of these fields, there were thus exhibited, in a single hour, without moving the telescope, four thousand eight hundred distinct stars! But by moving the instrument at the same time in the vertical direction, he found that in a space of the firmament, not more than fifteen degrees long, by four broad, he saw fifty thousand stars, large enough to be individually visible and distinctly counted! The surprising character of this result will be more adequately appreciated, if it is remembered that this number of stars thus seen in the space of the heavens, not more than thirty diameters of the moon's disc in length, and eight in breadth, is fifty times greater than all the stars taken together, which the naked eye can perceive at any one time in the heavens, on the most serene and unclouded night!

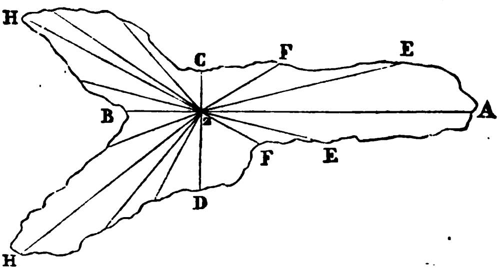
On presenting the telescope to the richer portion of the *via lactea*, Herschel found, as might be expected, much greater numbers of stars. In a single field he was able to count 588 stars; and for fifteen minutes, the firmament being moved before his telescope by the diurnal motion, no diminution of number was apparent; the number seen at any one time being greater than can be seen by the naked eye, on the entire firmament, except on the clearest nights.

75. It may be considered as established by a body of analogical evidence, having all the force of demonstration, that the fixed stars are self-luminous bodies, similar to our sun; and that although they may differ more or less from our sun and from each other in magnitude and intrinsic lustre, they have a certain average magnitude; and that, therefore, in the main, the great

differences which are apparent in their brightness, is to be ascribed to difference of distance. Assuming, then, that they are separated from each other by distances analogous to their distances from the sun, itself a star, the general phenomena which have been described above, involving the rapid increase of stellar density in approaching the galactic plane, combined with the observed form of the milky way, which, following the galactic plane in its general course, departs nevertheless from it at some points, bifurcates resolving itself into two diverging branches at others, and at others throws out irregular off-shoots, conducted Sir W. Herschel to the conclusion, that the stars of our firmament, including those which the telescope renders visible, as well as those visible to the naked eye, instead of being scattered indifferently in all directions around the solar system through the depths of the universe, form a stratum of definite form and dimensions, of which the thickness bears a very small proportion to the length and breadth, and that the sun and solar system is placed within this stratum, very near its point of bifurcation, relatively to its breadth near its middle point, and relatively to its thickness (as would appear from the more recent observations) nearer to its northern than to its southern surface.

Let A C H D, fig. 9, represent a rough outline of a section of such a stratum, made by a plane passing through or near its centre.

Fig. 9.



Let A B represent the intersection of this with the plane of the galactic circle, so that, *z* being the place of the solar system, *z* C will be the direction of the north, and *z* D that of the south galactic pole. Let *z* H represent the two branches which bifurcate from the chief stratum at B. Now, if we imagine visual lines to be drawn from *z* in all directions, it will be apparent that those *z* C and *z* D, which are directed to the galactic poles, pass through a thinner bed of stars than any of the others; and since *z* is supposed to be nearer to the northern than to the southern side of the stratum, *z* C will pass through a less thickness of stars than z D. As the visual lines are inclined at greater and greater angles to z A, their length rapidly decreases, as is evident by comparing z A, z E, and z F, which explains the fact that while the stars are as thick as powder in the direction z A, they become less so in the direction z E, and still less in the direction z F, until at the poles in the directions z C and z D, they become least dense.

On the other side, z B being less than z A, a part of the galactic circle is found at which the stars are more thinly scattered; but in two directions, z H intermediate between z B and the galactic poles, they again become nearly as dense as in the direction z A.

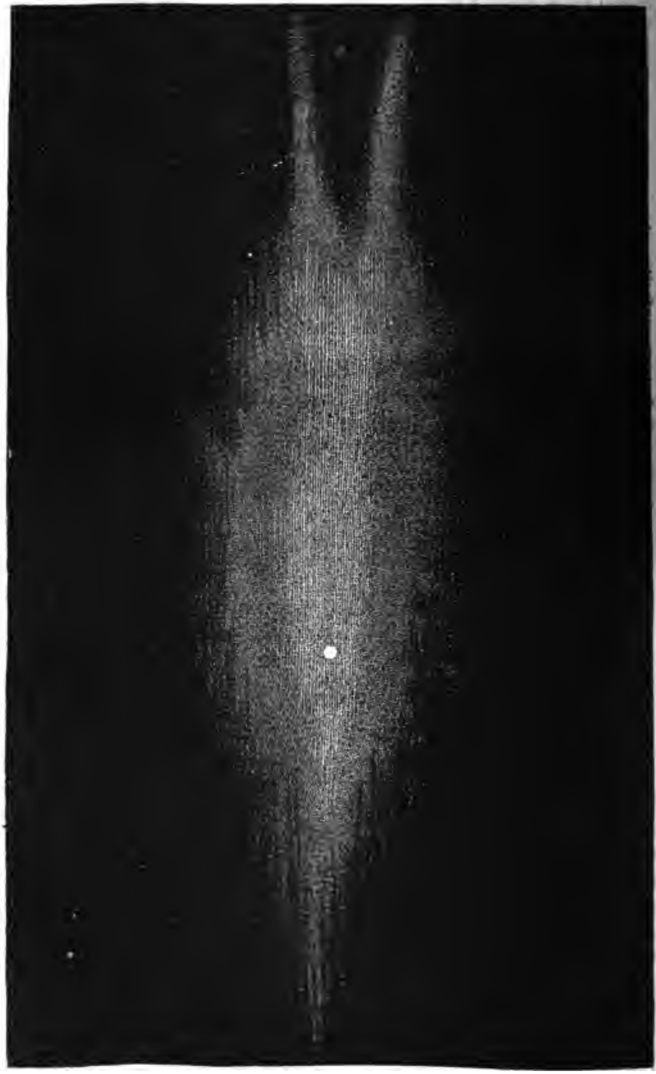
This illustration must, however, be taken in a very general sense. No attempt is made to represent the various off-shoots and variations of length, breadth, and depth of the stratum measured from the position of the solar system within it, which have been indicated by the telescopic *soundings* of Sir W. Herschel and his illustrious son, whose wondrous labours have effected what promises in time, by the persevering researches of their successors, to become a complete analysis of this most marvellous mass of systems. Meanwhile it may be considered as demonstrated, that it consists of myriads of stars clustered together:—

> "A broad and ample road, whose dust is gold,
> And pavement stars, as stars to us appear;
> Seen in the galaxy that Milky Way,
> Like to a circling zone powder'd with stars."—MILTON.

The appearance which this mass of stars would present if viewed from a position directly above its general plane, and at a sufficient distance to allow its entire outline to be discerned, was represented by Sir William Herschel as resembling the starry stratum sketched in fig. 10.

He considered that it was probable that the *thickness* of this *bed of stars* was equal to about eighty times the distance of the nearest of the fixed stars from our system; and supposing our sun to be near the middle of this thickness, it would follow that the stars on its surface in a direction perpendicular to its general plane would be at the fortieth order of distance from us. The stars placed in the more remote edges of its *length* and *breadth* he estimated to be in some places at the nine-hundredth order of distance from us, so that its extreme length may be said to be in round numbers about 2000 times the distance of the nearest fixed stars from our system. Such a space light would take 20000 years to move over, moving all that time at the rate of nearly 200000 miles between every two ticks of a common clock!

Fig. 10.



Figs. 35, 36.—SPIRAL NEBULÆ, AS SHOWN BY THE GREAT ROSSE TELESCOPE.

THE STELLAR UNIVERSE.

CHAPTER V.

STELLAR CLUSTERS AND NEBULÆ: 76. The stars of the firmament a stellar cluster.—77. Such clusters innumerable.—78. Their distribution on the firmament.—79. Their constitution.—80. Their apparent and real forms.—81. Nebulæ.—82. Double nebulæ.—83. Planetary nebulæ.—84. Annular nebulæ.—85. Spiral nebulæ.

STELLAR CLUSTERS AND NEBULÆ.

76. It appears, then, that our sun is an individual star, forming only a single unit in a cluster or mass of many millions of other similar stars; that this cluster has limited dimensions, has ascertainable length, breadth, and thickness, and, in short, forms what may be expressed by a *universe of solar systems*. The mind, still

unsatisfied, is as urgent as before in its questions regarding the *remainder of immensity*. However vast the dimensions of this mass of suns be, they are nevertheless finite. How stupendous soever be the space included within them, it is still *nothing* compared to the immensity which lies outside! Is that immensity a vast solitude? Are its unexplored realms dark and silent? Has Omnipotence circumscribed its agency, and has Infinite Beneficence left those unfathomed regions destitute of evidence of His power?

That the infinitude of space should exist without a purpose, unoccupied by any works of creation, is plainly incompatible with all our notions of the character and attributes of the Author of the universe, whether derived from the voice of revelation or from the light of nature. We should therefore infer, even in the absence of direct evidence, that *some* works of creation are dispersed through those spaces which lie beyond the limits of that vast stellar cluster of which our system is a part. Nay, we should be led, by the most obvious analogies, to conjecture that *other stellar clusters*, like our own, are dispersed through immensity, separated probably by distances as much greater than those which intervene between star and star, as the latter are greater than those which separate the bodies of the solar system. But if such distant clusters existed, it may be objected, that they must be visible to us; that although diminished, perhaps, to mere spots on the firmament, they would still be rendered apparent, were it only as confused whitish patches, by the telescope; that as the stars of the milky way assume to the naked eye the appearance of mere whitish nebulosity, so the far more distant stars of other clusters, which cannot be perceived at all by the naked eye, would, to telescopes of adequate power, present the same whitish nebulous appearance; and that we might look forward without despair to such augmentation of the powers of the telescope as may even enable us to perceive them to be actual clusters of stars.

77. Such anticipations have accordingly been realised. In various parts of the firmament objects are seen which, to the naked eye, appear like stars seen through a mist, and sometimes as nebulous specks, which might be, and not infrequently have been, mistaken for comets. With ordinary telescopes these objects are visible in very considerable numbers, and were observed nearly a century ago. In the *Connaissance des Temps*, for 1784, Messier, then so celebrated for his observations on comets, published a catalogue of 103 objects of this class, of many of which he gave drawings, with which all observers who search for comets ought to be familiar, to avoid being misled by their resemblance to them. The improved powers of the telescope speedily disclosed to astro-

nomers the nature of these objects, which, when examined by sufficient magnifying powers, prove to be masses of stars clustered together in a manner identical with that cluster in which our sun is placed. They appear as they do, mere specks of whitish light, because of their enormous distance.

78. These objects are not dispersed fortuitously and indifferently on all parts of the heavens. They are wholly absent from some regions, in some rarely found, and crowded in amazing profusion in others. Their disposition, however, is not like that of the stars in general, determined by a great circle of the sphere and its poles. It was supposed that they showed a tendency to crowd towards a zone at right angles to the galactic circle, but a careful comparison of their position does not confirm this. According to Sir W. and Sir J. Herschel, the nebulæ prevail most around the following parts of the celestial sphere :—

1 The North Galactic Pole.
2 Leo major.
3 Leo minor.
4 Ursa major.
5 Canes Venatici.
6 Coma Berenici.
7 Bootes (precedingly).
8 Virgo (head, wings, and shoulder).

The parts of the heavens, on the other hand, where they are found in the smallest numbers, are,—

1 Aries.
2 Taurus.
3 Orion (head and shoulders).
4 Auriga.
5 Perseus.
6 Camelopardus.
7 Draco.
8 Hercules.
9 Serpentarius (northern part).
10 Serpens (tail).
11 Aquila (tail).
12 Lyra.

In the southern hemisphere their distribution is more uniform.

79. What those objects are, and of what they severally consist, admits of no reasonable doubt. So far as relates to the stellar clusters, their constituent parts are visible. They are, as their name imports, masses of stars collected together at certain points in the regions of space which stretch beyond the limits of our own cluster, and are by distance so reduced in their visual magnitude, that an entire cluster will appear to the naked eye, if it be visible at all, as a single star, and when seen with the telescope will be included within the limit of a single field of view.

Different clusters exhibit their component stars seen with the same magnifying power more or less distinctly. Thus, for example, fig. 11 represents the appearance of a cluster seen with a powerful telescope, in which the stars appear like grains of silver powder.

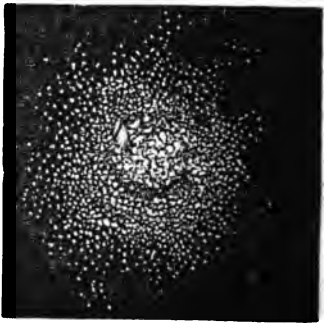
In fig. 12, on the other hand, the component stars are distinct, and those of fig. 13 still more so.

This may be explained either by difference of distance, or by the supposition that they may consist of stars of different real magnitudes, and crowded more or less closely together. The former supposition is, however, by far the more natural and probable.

The appearance of the stars composing some of the clusters is quite gorgeous. Sir J. Herschel says, that the cluster which surrounds κ Crucis in the southern hemisphere, occupies the 48th part of a square degree, or about the tenth part of the superficial magnitude of the moon's disc, and consists of about 110 stars from the 7th magnitude downwards, eight of the more conspicuous stars being coloured with various tints of red, green, and blue, so as to give to the whole the appearance of a rich piece of jewellery.

Fig. 11.

Fig. 12.



Cluster compared with cluster show all gradations of smallness and closeness of the component stars, until they assume the appearance of patches of starry powder. These varieties are more obviously ascribable to varying distances.

Fig. 13.

Then follow those patches of starry light which are seen in so many regions of the heavens, and which have been denominated nebulæ, appearing with very different degrees of magnitude and brightness. Telescopic views of three such are given in figs. 14, 15, and 16.

That these are still clusters, of which the component stars are indistinguishable by reason of their remoteness, there are the strongest evidence and most striking analogies to prove. Every augmentation of power and improvement of efficiency the telescope receives, augments the number of nebulæ which are converted by that instrument into clusters. Nebulæ which were irresolvable before the time of Sir W. Herschel, yielded in large numbers to the powers of the instruments which that observer brought to bear upon them. The labours of Sir J. Herschel, the colossal telescopes constructed by Lord Rosse, and the erection of observatories in multiplied numbers in climates and under skies more favourable to observation, have all tended to augment the number of nebulæ which have been resolved, and it may be expected that this progress will continue, the resolution of these objects into stellar clusters being co-extensive with the improved powers of the telescope and the increased number and zeal of observers.

Fig. 14.

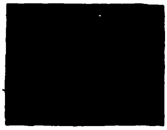
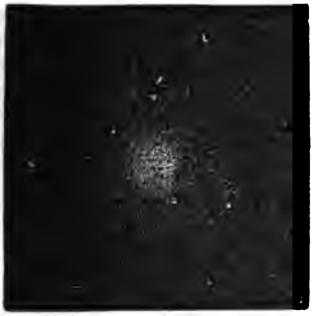


Fig. 15.

Fig. 16.



A theory was put forward to explain these objects, based upon views not in accordance with what has just been related. It was assumed hypothetically that the nebulous matter was a sort of luminous fluid diffused through different parts of the universe; that by its aggregation on certain laws of attraction, solid luminous masses in process of time were produced, and that these nebulæ grew into clusters.

It would not be compatible with the limits of this Tract, and the objects to which it is directed, to pursue this speculation through its consequences, to state the arguments by which it is supported and opposed; and it is the less necessary to do so, seeing that such an hypothesis is not needed to explain appearances which are so much more obviously and simply explicable by the admission of a gradation of distances.

80. The apparent forms of these objects are extremely various, and subject to most extraordinary and unexpected changes, according to the magnifying power under which they are viewed. This ought, however, to excite no surprise. The telescope is an expedient by which a well-defined and strongly illuminated optical image of a distant object is formed so close to the observer, that he is enabled to view it with microscopes of greater or less power, according to the perfection of its definition, and the intensity of its illumination. Now, it is known to all who are familiar with the use of the microscope, that the apparent form and structure of an object change in the most remarkable and unexpected way when viewed with different microscopic powers. The blood, for example, which viewed with the naked eye, or with low powers, is a uniformly red fluid, appears as a pellucid liquid, having small red discs floating in it, when seen with higher powers. Like effects are manifested in the cases of the nebulæ, when submitted to examination with different and increasing magnifying powers, of which we shall presently show many striking examples.

Stellar clusters are generally roundish or irregular patches. The stars which compose them are always much more densely crowded together, in going from the edges of the cluster towards the centre, so that at the centre they exhibit a perfect blaze of light.

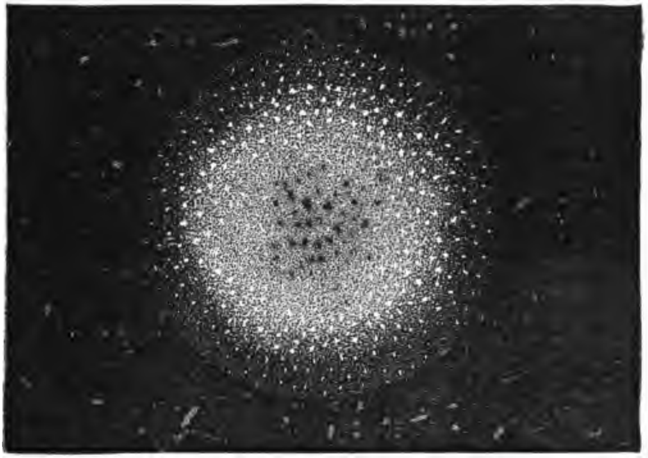
The apparent form is that of a section of the real form, made by a plane at right angles to the visual ray. If the mass had a motion of rotation, or any other motion by which it would change this plane, so as to exhibit to the eye successively different sections of it, its real form could be inferred as those of the planets have been. But there are no discoverable indications of any such motion in these objects. Their real forms, therefore, can only be conjectured from comparing their apparent forms with their structural appearance.

The clusters having round apparent forms, and of which the stars are rapidly more dense towards the centres, are inferred to be either globular or spheroidal masses of stars, the greater apparent density in passing from the edges to the centre being explained by the greater thickness of the mass, in the direction of the visual line. Clusters of irregular outline which show also a density increasing inwards, are also inferred, for like reasons, to be masses of stars, whose dimensions in the direction of the visual rays correspond with their dimensions in the direction at right angles to those rays.

In fig. 17 is represented a cluster observed and delineated by Sir J. Herschel. It is situated at about 1½° south of the celestial equator, and about 38½° east of the autumnal equinoctial point. It occupies a space on the heavens, the diameter of which is equal to the 300th part of that of the full moon. Sir John Herschel, who observed it with a reflecting telescope of nine inch aperture, describes its appearance as that of a most superb cluster of stars of the fifteenth magnitude, so condensed towards the centre as to become a perfect blaze of light. He compares it to a mass of fine luminous sand.

Nothing can be more striking than the different appearances which the same objects have presented, when viewed by the telescopes of Sir John Herschel and the more powerful instruments constructed by the Earl of Rosse. In fig. 18 we have given the same cluster as it appears in one of Lord Rosse's telescopes.

Fig. 17.

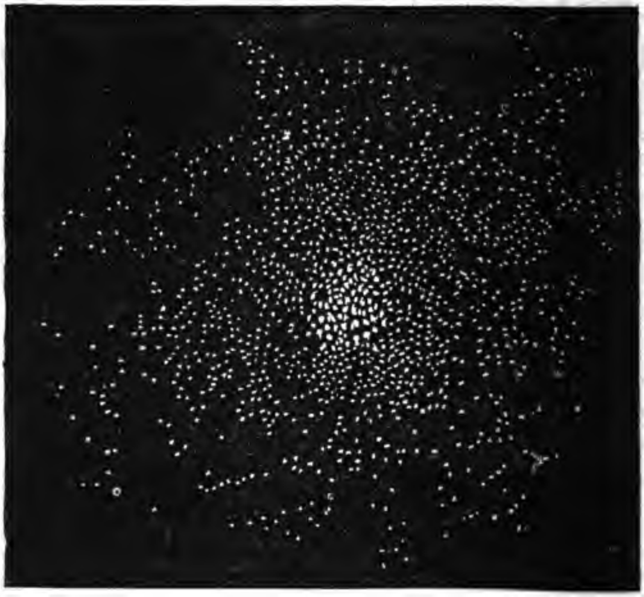


The stars which, in Sir John Herschel's instruments, are crowded together so as to produce a blaze of light, are completely separated by the telescope of Lord Rosse.

In fig. 19 is represented an object as delineated by Sir John Herschel, which appears in his telescope as a fine oval nebula, the length of which is about the eighth, and the breadth the tenth, part of the moon's diameter. This nebula is situated a few degrees north of the constellation of Orion, between it and Aldebaran.

In fig. 20, the same object is delineated as shown by Lord Rosse's telescope. Here a still greater change of appearance is produced than in the former case. The oval form is lost, and converted into that which is shown in the figure. The object is studded with innumerable stars, which are projected upon a nebulous ground. This nebulous ground would most evidently be resolved into stars if viewed with still higher powers.

Fig. 18.



81. The nebulæ, properly so called, present a much greater variety of form than the stellar clusters. Some are circular, with more or less precision of outline. Some are elliptical, the oval outline having degrees of excentricity infinitely various, from one which scarcely differs from a circle, to one which is compressed into a form not sensibly different from a straight line. In short, the minor axis of the ellipses bears all proportions to the major axis, until it becomes a very small fraction of the latter.

To infer the real from the apparent forms of these objects with any certainty, there are no sufficient data. But in the cases in which the brightness increases rapidly towards the centre, which it very generally does, it may be probably conjectured that their forms are globular or spheroidal, for the reasons already explained

Fig. 19.

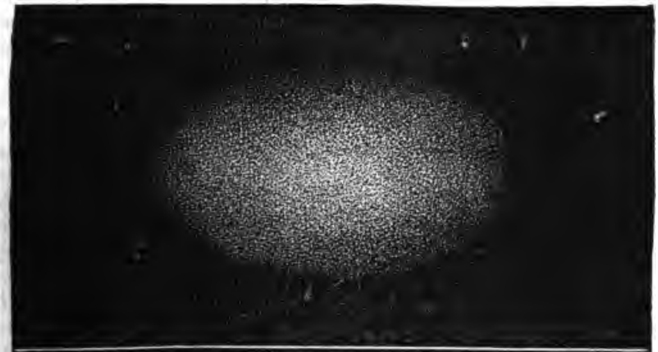


Fig. 20.

in relation to the clusters, and this becomes the more probable when it is considered, that these nebulæ are in fact clusters, the stars of which are reduced to a nebulous patch by distance.

Nevertheless, these nebulæ may be strata of stars, of which the thickness is small compared with their other dimensions; and supposing their real outline to be circular, they will appear elliptical if the plane of the stratum be inclined to the visual line, and more or less excentrically elliptical, according as the angle of inclination is more or less acute. In cases in which the brightness does not increase in a striking degree from the edges inwards, this form is more probable than the globular or the spheroidal.

Nebulæ may be conveniently classed according to their apparent form and structure; but whatever arrangement may be adopted, these objects exhibit such varieties, assume such capricious and irregular forms, and undergo such strange and unexpected changes of appearance according to the increasing power of the telescope with which they are viewed, that it will always be found that great numbers of them will remain unavoidably unclassified.

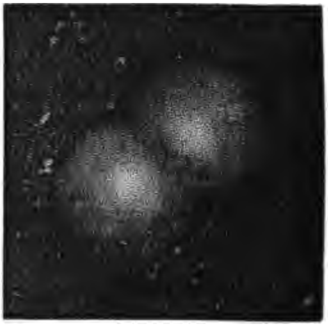
82. Like individual stars, nebulæ are found to be combined in pairs too frequently to be compatible with the supposition, that such combinations arise from the fortuitous results of the small obliquity of the visual rays, which causes mere optical juxtaposition.

In figs. 21, 22, 23, and 24, four double nebulæ of this class are represented.

In fig. 21, the visual line passes between them without touching either, and they are consequently seen completely separated. They are in this case equal in magnitude.

Fig. 21.

Fig. 22.



In fig. 22 they are also equal in magnitude, but the distance between their centres being less than their diameter, they partially overlay each other.

In figs. 23 and 24 they are unequal, and also partly overlay each other.

Fig. 23.

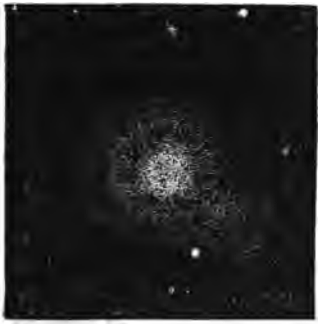
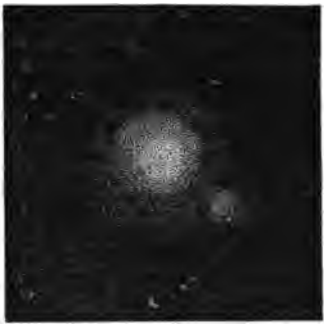


Fig. 24.



These double nebulæ are generally circular in their apparent, and therefore probably globular in their real form. In some cases they are resolvable clusters.

That such pairs of clusters are physically connected does not admit of a reasonable doubt, and it is highly probable that, like the binary stars, they move round each other, or round a common centre of attraction, although the apparent motion attending such revolution is rendered so slow by their immense distance that it can only be ascertained after the lapse of ages.

83. *Planetary Nebulæ.*—This class of objects derive their name from their close resemblance to planetary discs. They are in general either circular or very slightly oval. In some cases the disc is sharply defined, in others it is hazy and nebulous at the edges. In some the disc shows a uniform surface, and in some it has an appearance which Sir J. Herschel describes by the term *curdled*.

There is no reason to doubt that the constitution of these objects is the same as that of other nebulæ, and that they are in fact clusters of stars which by mutual proximity and vast distance are reduced to the form of planetary discs.

Nebulæ of this class, which are not numerous, present some remarkable peculiarities of appearance and colour. It has been already observed that, although the companion of a red individual of a double star appears blue or green, it is not certain that this is its real colour, the optical effect of the strong red of its near neighbour being such as would render a white star apparently blue or green, and no example of any single blue or green star has ever been witnessed. The planetary nebulæ, however, present some very remarkable examples of these colours. Sir J. Herschel indicates a beautiful instance of this, in a planetary nebula situate in the southern constellation of the Cross. The apparent diameter is 12″, and the disc is nearly circular, with a well-defined outline, and a "fine and full blue colour verging somewhat upon green." Several other planetary nebulæ are of a like colour, but more faint.

The magnitudes of these stupendous masses of stars may be conjectured from their probable distances. One of the largest, and therefore probably the nearest of them, is situate near the star β Ursæ majoris (one of the pointers). Its apparent diameter is 2′ 40″. Now, if this were only at the distance of 61 Cygni, whose parallax is known, it would have a diameter equal to seven times that of the extreme limit of the solar system; but as it is certain that its distance must be many times greater, it may be conceived that its dimensions must be enormous.

In fig. 25 is represented a small nebula of this class, drawn by Sir J. Herschel. It is situate near the star δ in the constellation Hercules (R A, $17^h\ 45^m$ N P D, 66° 53′), and is described as having a perceptible disc from 1″ to 1½″ in diameter, surrounded by a faint nebula.

Fig. 25.

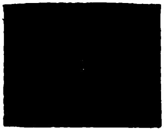


Fig. 26.

In fig. 26 is another similar object, situated a little to the north of the constellation of Lyra (R A $19^h\ 40^m$ N P D 39° 54′). A most curious object. A star of the 11th magnitude, surrounded by a very bright and perfectly round planetary nebula of uniform light. Diameter in R A 3·5″, perhaps a very little hazy at the edges. (Herschel.)

In fig. 27 is represented another of the same class, situated in (R A $13^h\ 29^m$ N P D 107° 1′) the constellation Virgo near the bright star *Spica*. Its entire diameter is 2′, being the 15th of that of the moon, and the diameter of the bright central part 10″ to 15″. It is described as a faint large nebula losing itself quite imperceptibly; a good type of its class. (Herschel.)

In fig. 28 is a nebula, situate in (R A $10^h\ 28^m$ N P D 35° 36′). It is described as a bright round nebula, forming almost a disc 15" diameter, surrounded by a very feeble atmosphere. (Herschel.)

Fig. 27.

Fig. 28.

84. *Annular Nebulæ.*—A very few of the nebulæ have been observed to be annular. Until lately there were only four. The telescopes of Lord Rosse have, however, added five to the number, by showing that certain nebulæ formerly supposed to be small round patches are really annular. It is extremely probable, that many others of the smaller class of round nebulæ will prove to be annular, when submitted to further examination with telescopes of adequate power and efficiency.

In fig. 29 one of this class is given, the situation of which is (R A 8^h 47^m N P D 57° 11′) between the constellations of Gemini and Cancer. This object, drawn by Sir J. Herschel, is the annular nebula between β and γ Lyræ. He estimates its diameter at 6″·5. The annulus is oval, its longer axis being inclined at 57° to the meridian. The central vacuity is *not black*, but filled with a

Fig. 29.

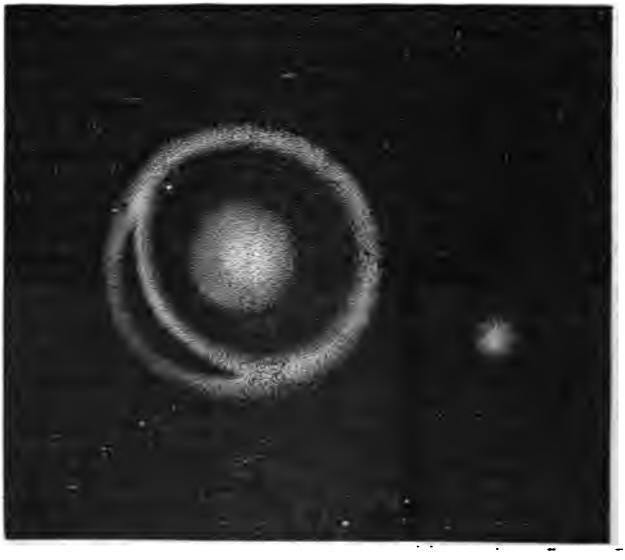
Fig. 30.

nebulous light. The edges are not sharply cut off, but ill defined; they exhibit a curdled and confused appearance, like that of stars out of focus. He considers it not well represented in the drawing.

Fig. 30 is the same object as shown in the telescope of Lord Rosse. This drawing was made with the smaller telescope, three feet aperture, before the great telescope had been erected. The nebula was observed seven times in 1848, and once in 1849. With the large telescope, the central opening showed considerably more nebulosity than it appeared to have with the smaller instrument. It was also noticed, that several small stars were seen around it with the large instrument, which did not appear with the smaller one, from which it was inferred that the stars seen in the dark opening of the ring may possibly be merely accidental, and have no physical relation to the nebula. In the annulus near the extremity of the minor axis, several minute stars were visible.

85. *Spiral Nebulæ.*—The discovery of this class of objects, the most extraordinary and unexpected which modern research has yet disclosed in stellar astronomy, is due to Lord Rosse. Their general form and character may be conceived by referring to those represented in figs. 32 and 34. These extraordinary forms are so entirely removed from all analogy with any of the phenomena presented either in the motions of the solar system, or the comets, or those of any other objects to which observation has been directed, that all conjecture as to the physical condition

Fig. 31.



of the masses of stars which could assume such forms would be vain. The number of instances as yet detected, in which this form prevails, is not great; but it is sufficient to prove that the phenomenon, whatever be its cause, is the result of the operation of some general law. It is pretty certain, that when the same powerful instruments which have rendered these forms visible in objects which had already been so long under the scrutiny of the most eminent observers of the last hundred years, including Sir W. and Sir J. Herschel, aided by the vast telescopic powers at their disposition, without raising even a suspicion of their real form and structure, have been applied to other nebulæ, other cases of the same phenomenon will be brought to light. In this point of view it is much to be regretted, that the telescopes of Lord Rosse cannot have the great advantage of being used under skies more favourable to stellar researches, since the discovery of such forms as these not only requires instruments of such power as Lord Rosse alone possesses at present, but also the most favourable atmospheric conditions.

In connection with this class of objects, and indeed with the nebulæ generally, one of the most remarkable is situate (R A 13^h 33^m N P D 41° 56′); as shown in fig. 31, it was observed and drawn by Sir John Herschel. "This is," says that eminent astronomer, "in many respects, one of the most remarkable and interesting of its class, and has been submitted to elaborate examination by all the eminent observers." The distance of the centre of the small nebula from that of the large one, is given by Messier, as 4′ 35″, which may serve as a *modulus* for its other dimensions. It was described by Sir W. Herschel as a bright round nebula, surrounded by a halo or glory, and attended by a companion. Sir J. Herschel observed this object, and represented it as in the figure. He noticed the partial division of the ring, as if it were split, as its most remarkable and interesting feature, and inferred that, supposing it to consist of stars, the appearance it would present to an observer, placed on a planet attached to one of them excentrically situate towards the north preceding quarter of the central mass, would be exactly similar to that of the milky way as seen from the earth, traversing in a manner precisely similar the firmament of large stars, into which the central cluster would be seen projected, and (owing to its greater distance) appearing like it to consist of stars much smaller than those in other parts of the heavens. "Can it be," asks Sir J. Herschel, "that we have here a brother system, bearing a real physical resemblance and strong analogy of structure to our own?" Sir J. Herschel further argues, that all idea of symmetry caused by rotation must be relinquished, considering that the elliptical form of the inner subdivided portion indicates with extreme probability an elevation of that part above the plane of the rest; so that the real form must be that of a ring split through half its circumference, and having the split portions set asunder at an angle of 45°.

Fig. 32 is the same object as shown by Lord Rosse's telescope. This shows, in a striking manner, how entirely the appearances of these objects are liable to be varied by the increased magnifying power and greater efficiency of the telescope through which they are viewed. It is evident, that very little resemblance or analogy is discoverable between fig. 31 and fig. 32. Lord Rosse, however, says that if Sir John Herschel's be placed as it would be seen with a Newtonian telescope, the bright convolutions of the spiral shown in his own would be recognised in the appearance which Sir J. Herschel supposed to be that which would be produced by a split or divided ring. Lord Rosse further observes that, with each increase of optical power, the structure of this object becomes more complicated and more unlike anything which could be supposed to be the result of any form of dynamical law of which we find a counterpart in our system. The connection of the companion with the principal nebula, of which there is not the least doubt, and which is represented in the sketch, adds, in Lord Rosse's opinion, if possible, to the difficulty of forming any conceivable hypothesis. That such a system should exist without internal movement he considers in the last degree improbable. Our conception may be aided, by uniting with the idea of motion the effects of a resisting medium; but it is impossible to imagine such a system in any point of view, as a case of mere statical equilibrium. Measurements he therefore considers of the highest interest, but of great difficulty.

Fig. 22.

Fig. 50.

Fig. 51.

THE STELLAR UNIVERSE.

CHAPTER VI.

Spiral nebulæ (continued).—86. Number of nebulæ.—87. The Dumb-Bell nebula as observed by Sir J. Herschel and Lord Rosse.—88. Various nebulæ figured by the same observers.—89. Large irregular nebulæ.—90. Rich cluster in the Centaur.—91. The great nebula in Orion.—92. The great nebula in Argo.—93. Magellanic clouds.

In fig. 33 is reproduced a drawing by Sir J. Herschel of a large nebula having a diameter estimated by him at 3′, or a tenth of that of the moon. This object is situate in R A 9^h 22^m N P D 67° 45′, and therefore near the northern part of the constellation of Leo minor. This is described by Sir John Herschel as a very bright extended nebula, with an approach to a second nucleus, which, however, is very faint.

Fig. 34 is the same object as shown by Lord Rosse's telescope. This object was first observed with the great telescope, 24th March, 1846, when a tendency to an annular or spiral form was discovered. On the 9th March, 1848, in more favourable weather, the spiral form was distinctly seen in an oblique direction. The nebula was well resolved, particularly towards the centre, where it was very bright.

Another most extraordinary spiral nebula is shown in fig. 35, p. 17. It has been the subject of examination by all eminent observers

Fig. 33.

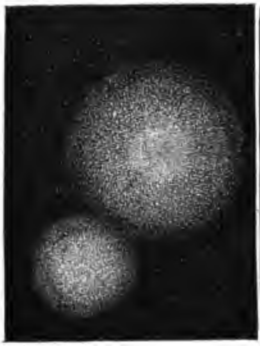


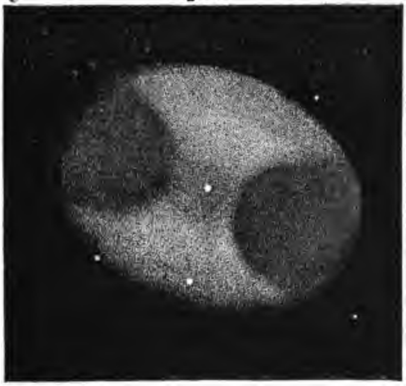
Fig. 34.

since the time of Messier, in whose catalogue it is No. 99. The spiral form of the nebula, represented in fig. 32, was discovered by Lord Rosse, in the early part of 1845. In the spring of 1846, that represented in the present figure was discovered. The spiral form is here also presented, but of a different character. Lord Rosse conjectures, that the nebula No. 2370, and 3239 of Herschel's southern catalogue, are very probably objects of a similar character. As Herschel's telescope did not reveal any trace of the form of this nebula, it is not surprising that it did not disclose the spiral form presumed to belong to the others, and it is not, therefore unreasonable to hope, according to his lordship, that whenever the southern hemisphere shall be re-examined with instruments of greater power, these two remarkable nebulæ will yield some interesting results.

Lord Rosse has discovered other spiral nebulæ, but they are comparatively difficult to be seen, and the greatest powers of the instrument are required to bring out the details.

In fig. 36 is another nebula having the spiral character, and a most singular form. Its situation is R A $1^h\ 24^m$ N P D 60° 31′, and is therefore in the northern part of the constellation Pisces. It is of great magnitude, having a diameter not less than half that of the moon. This object has been the subject of observation by all the eminent observers. Sir John Herschel describes it as enormously large, growing very gradually brighter towards the middle, and having a star of the 12th magnitude, north, following the nucleus, and being characterised by irregularities of light, and even by feeble subordinate nuclei and many small stars. The drawing represents it as seen with the more powerful

Fig. 37.



telescope of Lord Rosse. A tendency to a spiral form was distinctly seen on the 6th, 10th, and 16th September, 1849. The whole object was involved in a faint nebulosity, which probably extends past several knots which lie about it in different directions.

86. The forms and magnitudes of the nebulæ are so infinitely various, that it is impossible to reduce them to any definite classification. Their number also is quite unbounded. The catalogues of Sir J. Herschel contain above 4000, of which the places are assigned, and the magnitudes, forms, and apparent characters described. As observers are multiplied, and the telescope improved, and especially when the means of observation have been extended to places that are more favourable for such observations, it may be expected that the number observed will be indefinitely augmented.

87. In fig. 37, we have reproduced the drawing of a well-known nebula by Sir John Herschel. This has been called, from its apparent form, the Dumb Bell nebula. Its situation is R A $19^h 52^m$ N P D 67° 44′, and consequently between the constellations of Vulpa minor and Lyra. Sir John Herschel describes it as a nebula shaped like a dumb-bell, double-headed shot, or hour-glass, the elliptic outline being completed by a more feeble nebulous light. The axis of symmetry through the centres of the two chief masses inclined at 30° to the meridian. Diameter of elliptic light from 7′ to 8′. Not resolvable, but four stars are visible on it, of the 12th, 13th, and 14th magnitude. The southern

head is denser than the northern. This extraordinary object was

Fig. 38.

also observed by Sir W. Herschel, who recognised the same

Fig. 39.

peculiar form. Sir J. Herschel considers that the most remarkable circumstance attending it is the faint nebulosity which fills up the lateral concavities of its form, and in fact converts them into protuberances, so as to render the whole outline a regular ellipse, having for its shorter axis the common axis of the two bright masses. If it be regarded as a mass in rotation, it is around this shorter axis it must revolve. In that case, he considers that its real form must be that of an oblate spheroid; and as it does not follow that the brightest portions must be of necessity the densest, this supposition would not be incompatible with dynamical laws, at least supposing its parts to be capable of exerting pressure on each other. But if it consist of distinct stars this cannot be admitted, and we must then have recourse to other suppositions to account for the maintenance of its form. Sir John Herschel, it will be observed, failed to resolve this nebula.

Fig. 38 is the same object as shown by the telescope of Lord Rosse, three feet aperture, twenty-seven feet focal length.

Fig. 39 is the same object as shown with the great telescope of Lord Rosse, six feet aperture, fifty-three feet focal length.

The difference between these two representations and that given by Sir John Herschel of the same object, will illustrate in a very striking manner the observations already made on the effects of different magnifying and defining powers upon the appearance of the object under examination. These three figures could scarcely be conceived to be representations of the same object.

To explain the difference observable between the drawing fig. 38, made with the smaller telescope, and the drawing fig. 39, made with the larger instrument, Lord Rosse observes, that while the application of a high magnifying power brings out minute stars not visible with lower powers, it completely extinguishes nebulosity which the lower powers render visible. The optical reason for this will be easily perceived; the circumstance was nevertheless overlooked when the observations were made from which the drawing fig. 38 was taken. Only one magnifying power, and that a very high one, was used on that occasion, the consequence of which was that, although the two knobs of the dumb-bell were more fully resolved, the nebulous matter filling the intermediate space, which Herschel considered to be the most remarkable feature of this nebula, was entirely extinguished in

Fig. 40.

the optical image. If on that occasion a second eye-piece had been used of lower power, the intermediate nebulous matter would have been seen, as represented in the drawing, and the drawing would be as perfect as, and nearly identical with, that

Fig. 41.

Fig. 42.

obtained with the greater telescope, a lower power being used.

Fig. 43

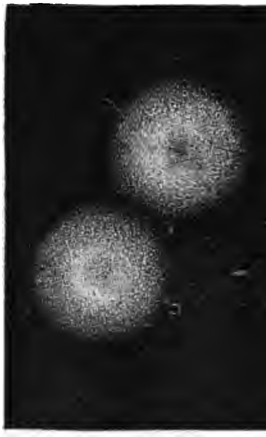


Fig 44

It will be observed that the general outline of this remarkable object which is so geometrically exact as seen with the inferior power used by Sir John Herschel, is totally effaced by the application of the higher powers used by Lord Rosse, and consequently Sir John Herschel's theoretical speculations based upon this particular form, must be regarded as losing much of their force, if not wholly inadmissible; and this is an example proving how unsafe it is to draw any theoretical inferences from apparent peculiarities of form or structure in these objects, which may be only the effect of the imperfect impressions we receive of them, and which, consequently, disappear when higher telescopic powers are applied. The case of the nebula represented in figs. 31 and 32, presents another striking example of the force of these observations.

88. In fig. 40 is a nebula drawn by Sir J. Herschel, who describes it as a faint large round nebula, which, by attentive examination, may be seen to be composed of excessively minute stars, appearing like points rubbed out. It is, in fact, a globular cluster.

In fig. 41, is a nebula situated in R A 22^h 56^m, N P D 78° 36′, and therefore in the southern part of the constellation of Pegasus. The length of this, as estimated by Sir J. Herschel, is 2′, or the 15th part of the moon's diameter, while the breadth is only half a minute, or the 60th part of the breadth of the lunar disk. It is shown in fig. 41 as it appeared in the telescope of Sir J. Herschel. It is described by him as pretty bright and resolvable, and extended between two small stars, having two very small stars visible in it.

In fig. 42 is shown the same object as seen in Lord Rosse's telescope. It was frequently observed, both by Lord Rosse himself and several of his friends, and the drawing represents the form with great accuracy. It was doubtful whether the form was strictly spiral, or whether it were not more properly annular.

In fig. 43 is shown a double nebula situate in R A 7^h 15^m, N P D 60° 11′, and therefore near the bright star Castor. It is drawn by Sir J. Herschel, who describes it as a curious bright double or an elongated bicentral nebula.

In fig. 44 is the same object as shown by Lord Rosse's telescope on 22nd December, 1848. A bright star was visible between the nebulæ from which tails and curved filaments issued. The existence of an annulus surrounding the two nebulæ was suspected.

In figs. 45, 46 are views of the same nebula, as seen by Sir J. Herschel and Lord Rosse. This object is situate in R A 11^h 10^m. N P D 75° 59′, and therefore between the two brightest stars of the constellation Leo. Its length is 4′ or about the 7th of the moon's diameter. It is described by Sir John Herschel as large, elliptical in form, with a round nucleus, and growing gradually brighter towards the middle.

In fig. 46 it is given as shown by Lord Rosse's telescope, 31st March, 1848. Described as a curious nebula, nucleus resolvable, having a spiral or annular arrangement about it. It was also observed with the same results on the 1st and 3rd April.

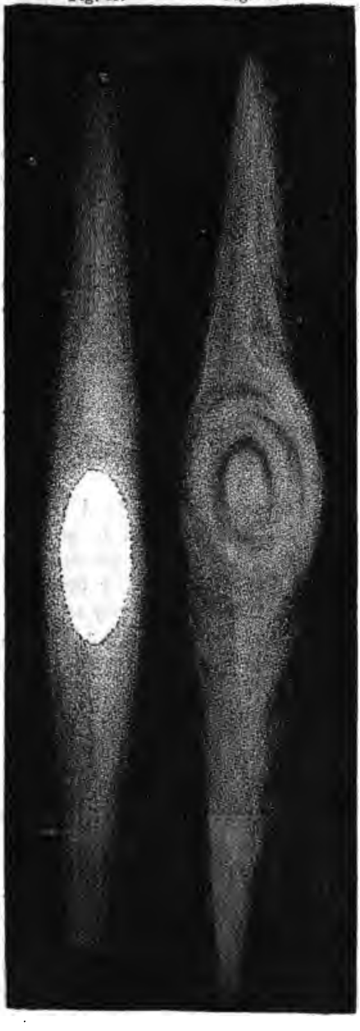


Fig. 45. Fig. 46.

A nebula, situate in R A 15^h 2^m, N P D 33° 35′, is shown in fig. 47, its length being 50″ and breadth 20″.

This nebula was not figured by Sir John Herschel; but is described by him as an object very bright, and growing much brighter towards the middle. The drawing represents the object as seen in Lord Rosse's telescope, in April, 1848. It is described by Lord Rosse as a very bright resolvable nebula, but that none of the component stars could be distinctly seen even with a magnifying power of 1000. A perfectly straight longitudinal division appears in the direction of the major axis of the ellipse. Resolvability was strongly indicated towards the nucleus. According to Lord Rosse, the proportion of the major axis to the minor axis was 8 to 1; much greater than the estimate of Sir John Herschel.

In figs. 48, 49 are given two views of the same nebula by Sir J. Herschel and Lord Rosse. Its situation is R A 12^h $33,^m$ N P D

Fig. 47

Fig. 48. Fig. 49

56° 30′. It is therefore near the northern limit of the Coma Berenices. It is described by Sir John Herschel as a nebula of enormous length, extending across an entire field of 15′, the nucleus not being well defined. It was preceded by a star of the tenth magnitude, and that again by a small faint round nebula, the whole forming a fine and very curious combination.

Fig. 49 is the same object as shown by Lord Rosse's telescope on 19th April, 1849. The drawing is stated to be executed with great care, and to be very accurate. A most extraordinary object, masses of light appearing through it in knots.

In fig. 50, p. 33, is represented a nebula situate in R A 6^h 30^m, N P

D. 81° 30′. It is therefore situate about midway between the bright star Procyon and the shoulders of the constellation Orion. This object is described by Sir John Herschel as a star of the 12th magnitude, with a bright cometic branch issuing from it, 60″ in length, forming an angle of 60° with the meridian, passing through it. The star is described as ill-defined, the apex of the nebula coming exactly up to it, but not passing it.

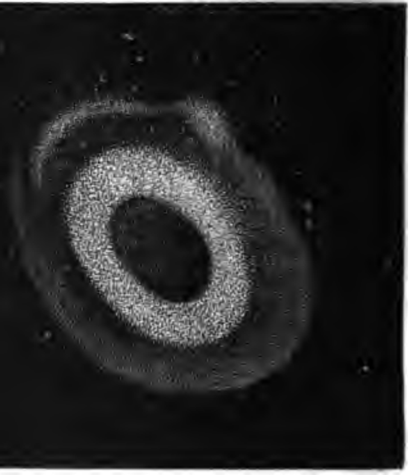
Fig. 51, p. 33, is the same object as seen with Lord Rosse's telescope on 16th January, 1850. Lord Rosse observed that the two comparatively dark spaces, one near the apex and the other near the base of the cone, are very remarkable.

In fig. 52, p. 193, Vol. vii., is represented a nebula situated in R A $11^h 5^m$, N P D 34° 3′, having a diameter equal to about the 90th part of that of the moon. It is drawn and described by Sir John Herschel as a large uniform nebulous disk, very bright and perfectly round, but sharply defined, and yet very suddenly fading away into darkness. A most extraordinary object.

Fig. 53, p. 193, Vol. vii., is the same object as shown by Lord Rosse's telescope. Two stars considerably apart, seen in the central part of the nebula. A dark penumbra around each spiral arrangement with stars as apparent centres of attraction. Stars sparkling in it and in the nebula resolvable. Lord Rosse saw two large and very dark spots in the middle, and remarked that all round its edge the sky appeared darker than usual.

Fig. 54.

Fig. 55.



OBSERVATIONS OF HERSCHEL AND LORD ROSSE.

In fig. 54 is represented a nebula situated in R A 23^h 18^m, N P D 48° 24′, as drawn by Sir John Herschel, who describes it as a fine planetary nebula. With a power of 240 it was beautifully defined, light, rather mottled, and the edges the least in the world unshaped. It is not nebulous, but looks as if it had a double outline, or like a star a little out of focus. It is perfectly circular.

Fig. 55 is the same object as shown in Lord Rosse's telescope, 16th—19th December 1848. A central dark spot surrounded by a bright annulus.

In fig. 56, p. 1, vol. viii., is a nebula situate in R A 20^h 54^m, N P D 102° 3′. Diameter 10″ to 12″ according to Herschel, but 25″ by 17″ according to Struve, who gives it a more oval form. This figure is that given by Sir John Herschel, who describes it as a fine planetary nebula with equable light and bluish white colour.

Fig. 57, p. 1, vol. viii., is the same object as shown by Lord Rosse's telescope. Like a globe surrounded by a ring such as that of Saturn, the usual line being in the plane of the ring.

In fig. 58 is a nebula drawn by Sir J. Herschel, situate in R A 7^h 19^m 8^s, N P D 68° 45′. Described as a star exactly in the centre of a bright circular atmosphere 25″ in diameter, the star being quite stellar, and not a mere nucleus, and is a most remarkable object.

Fig. 58.

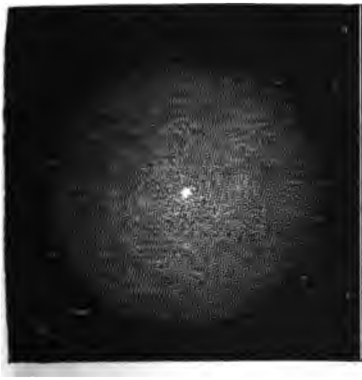


Fig. 59.

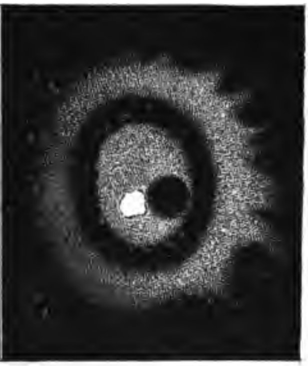


Fig. 59 is the same object as shown by Lord Rosse's telescope on 20th February, 1849; described by him as a most astonishing object. It was examined in January 1850, with powers of 700 and 900, when both the dark and bright rings seemed unequal in breadth.

In fig. 60 is represented a drawing by Lord Rosse, made with his large telescope, of a nebula situate in R A $5^h\ 27^m$, N P D 96° 2′. This nebula surrounds the small star ι Orionis, and has a diameter equal to about a tenth part of that of the moon.

Fig. 60.

89. All the nebulæ described above are objects generally of regular form, and subtending small visual angles. There are others, however, of a very different character, which cannot be passed without some notice. These objects cover spaces on the firmament, many nearly as extensive as, and some much more extensive than, the moon's disk. Some of them have been resolved. Of those which are larger and more diffused, some exhibit irregularly shaped patches of nebulous light, affecting forms resembling those of clouds, in which tracts are seen in every stage of resolution, from nebulosity irresolvable by the largest and most powerful telescopes, to stars perfectly separated like parts of the milky way, and "clustering groups sufficiently insulated and condensed to come under the designation of irregular and, in some cases, pretty rich clusters. But, besides these, there are also nebulæ in abundance, both regular and irregular; globular clusters, in every state of condensation, and objects of a nebulous character quite peculiar, which have no analogy in any other part of the heavens."*

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* Herschel, Outlines of Astronomy, p. 613.

90. The star ω Centauri presents one of the most striking examples of the class of large diffused clusters. It is nearly round, and has an apparent diameter equal to two-thirds of that of the moon. This remarkable object was included in Mr. Dunlop's catalogue ("Phil. Trans." 1828); but it is from the observations of Sir John Herschel, at the Cape, that the knowledge of its splendid character is derived. That astronomer pronounces it, beyond all comparison, the richest and largest object of the kind in the heavens. The stars composing it are literally innumerable; and as their collective light affects the eye hardly more than that of a star of the fifth magnitude, the minuteness of each of them may be imagined. The apparent magnitude of this object is such that, when it was concentric with the field of Sir J. Herschel's 20-feet telescope, the straggling stars at the edges were beyond the limit of the field. In stating that the diameter is two-thirds of the moon's disk, it must be understood to apply to the diameter of the condensed cluster, and not to include the straggling stars at the edges. When the centre of the cluster was brought to the edge of the field, the outer stars extended fully half a radius beyond the middle of it.*

The appearance of this magnificent object resembles that shown in fig. 18, only that the stars are much more densely crowded together, and the outline more circular, indicating a pretty exact globe as the real form of the mass.

91. *The great nebula in Orion.*—The position of this extraordinary object is in the sword-handle of the figure which forms the constellation of Orion. It consists of irregular cloud-shaped nebulous patches, extending over a surface about 40′ square; that is, one whose apparent breadth and height exceed the apparent diameter of the moon by about one-third, and whose superficial magnitude is, therefore, rather more than twice that of the moon's disk. Drawings of this nebula have been made by several observers, and engravings of them have been already published in various works.

In fig. 61 is given a representation of the central part of this object. The portion here represented has a height and breadth about one-sixth less than the diameter of the moon. An engraving upon a very large scale, of the entire extent of the nebula, with an indication of the various stars which serve as a sort of landmarks to it, may be seen by reference to Sir J. Herschel's "Cape Observations," accompanied by the interesting details of his observations upon it.

Sir J. Herschel describes the brightest portion of this nebula as

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* Cape Observations, p. 21.

Fig. 61.

resembling the head and yawning jaws of some monstrous animal, with a sort of proboscis running out from the snout. The stars scattered over it probably have no connection with it, and are doubtless placed much nearer to our system than the nebula, being visually projected upon it. Parts of this nebula, when submitted to the powers of Lord Rosse's telescope, show evident indications of resolvability.

92. An object of the same class is shown in fig. 62, p. 177, Vol. vii., and presenting like appearances; it is diffused around the star η in the constellation Argo, and formed a special subject of observation by Sir J. Herschel, during his residence at the Cape. An engraving of it on a large scale, giving all its details, may be seen in the "Cape Observations." The position of the centre of the nebula is, R A 10° 38′ 38″, N P D 148° 47′.

This object consists of diffused irregular nebulous patches, extending over a surface measuring nearly 7^m in right ascension, and 68′ in declination; the entire area, therefore, being equal to a square space, whose side would measure one degree. It occupies, therefore, a space on the heavens about five times greater than the disk of the moon.

The part of the nebula immediately surrounding the central star, is represented in fig. 62. The space here represented measures about one-fourth of the entire extent of the nebula, in declination, and one-third in right ascension, and about a twelfth of its entire magnitude.

No part of this remarkable object has shown the least tendency to resolvability. It is entirely compressed within the limits of that part of the milky way which traverses the southern firmament, the stars of which are seen projected upon it in thousands. Sir J. Herschel has actually counted 1200 of these stars projected upon a part of this nebula, measuring no more than 28′ in declination, and 32′ in right ascension, and he thinks that it is impossible to avoid the conclusion, that in looking at it we see through and beyond the milky way, far out into space through a starless region, disconnecting it altogether with our system.

93. The Magellanic clouds are two extensive nebulous patches also seen on the southern firmament, the greater called the *nubecula major*, being included between R A 4^h 40^m, and 6^h 0^m and N P D 156° and 162°, occupying a superficial area of 42 square degrees; and the other called the *nubecula minor*, being included between R A 0^h 21^m and 1^h 15^m and between N D P 162° and 165°, covering about 10 square degrees.

These nebulæ consist of patches of every character, some irresolvable, and others resolvable in all degrees, and mixed with clusters; in fine, having all the characters already explained in the cases of the large diffused nebulæ described above. So great is the number of distinct nebulæ and clusters crowded together in these tracts of the firmament, that 278, besides 50 or 60 outliers, have been enumerated by Sir J. Herschel, within the area of the nubecula major alone.

Fig. 20.—CAUCASIAN.

COMMON THINGS.

MAN.

CHAPTER I.

1. Physical condition of Man generally neglected.—2. The brain the organ of intelligence.—3. General view of the nervous system.—4. Structure of the brain.—5. The Facial Angle.—6. Its variation in different animals.—7. Recognised as an indication of intellectual power.—8. The advantages Man derives from the form of his members.—9. Prehensile and locomotive members.—10. Structure of the hand.—11. The bones of the arm and hand.—12. Wonderful play of the muscles and the movement of the fingers; example of piano-forte playing.—13. The lower members.—14. The leg and foot.—15. The erect position proper to man.—16. Man alone bimanous and bipedous.—17. Quadrumana.—18. Power of language.

1. ALTHOUGH it has been affirmed and quoted by generation after generation that

"The proper study of mankind is man,"

that study, even among the most cultivated, has been confined too exclusively to the social and political condition of our race, to the total neglect of the physical relations by which it is connected with the inferior species. Although these relations exhibit in a striking point of view all that we have in common with the rest of the animal kingdom, they render manifest not less conspicuously those which set us apart from, and exalt us above them. So profoundly impressed was the greatest of modern naturalists with the force of the evidence of man's superiority, derived merely from his physical organisation, that he maintained that, even according to the rigorous principles of inductive science based on physical and mechanical phenomena, without taking into consideration the possession of the reasoning faculty, man ought to be classified, not as a species of the order of vertebrated animals, but as an order apart, distinct from and independent of all other parts of organised nature, and presenting the anomalous example of being the sole genus of his order and the sole species of his genus.*

Nevertheless, our physical organisation differs but little in appearance from that of a considerable number of Mammifers,† that is, of the animals which suckle their young. The functions of nutrition with us and with them are alike, and the structure of the organs of sense present but few distinguishing peculiarities. Yet man is placed immeasurably above all other organised beings, a superiority which he owes, not altogether to the gift of reason and of language, but also, in a great degree, to the mechanical conformation of his members.

2. Physiologists have traced a general relation between the degree of intelligence manifested by different organised beings, and the volume and structure of the brain, not only when species is compared with species, but when individual is compared with individual: and some have pretended to push this induction even so far as to connect different parts of the brain with different faculties, passions, and tendencies, founding their conclusions partly on observations of the human brain in connection with the development of human character, and partly on the analogies observable between the human brain, passions, and tendencies, compared with the brain, passions, and tendencies of inferior animals. Hence has arisen that new branch of inquiry claiming a place in physiological science under the name of Phrenology.

However questions of this order may be decided, it has never been doubted that the brain is the organ of intelligence, thought, and feeling. It is the centre of the nervous system, and is connected with all parts of the body by thousands of nervous filaments.

3. Some notion of the manner in which these diverge from the brain and from all parts of the spinal cord, and ramify over all

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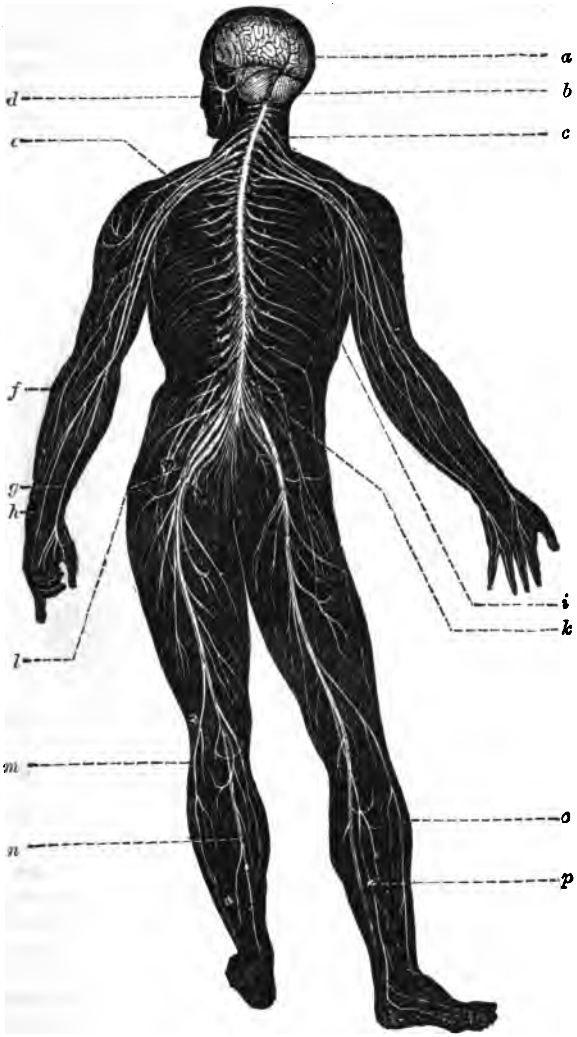
* Cuvier.

† From *mamma*, a "pap, or teat," and *fero*, "I bear."

the organs and members, may be obtained by the annexed figure, where *a* is the brain; *b*, the posterior part of that organ, called



the *cerebellum;* *c*, the spinal cord; *d*, the branch of nerves which ramifies over the face; *e*, that which goes to the arm; *f*, *g*, *h*, its ramifications over the lower arm and hand; *i*, those which spread over the trunk; *k*, *l*, those which lead to the leg and thigh; *m*, *n*, *o*, *p*, their ramifications over the leg and foot.

The innumerable nervous filaments which are thus spread over the entire system, and which at length become so minute as to be microscopic, are the messengers of thought, carrying the dictates of the will from the brain to all the members, which move in most absolute obedience to the commands thus received. They are also the conductors of sensation from all parts of the system to the brain, and are therefore divided into two classes; the first consisting of those which, carrying the dictates of the will to the movable members, are called *nerves of motion;* and the second, of those which, conveying sensation from all parts of the body to the brain, are called *nerves of sensation.* The practical proof that each of these classes of nerves is invested with the special functions here ascribed to them, is found in the fact, that if

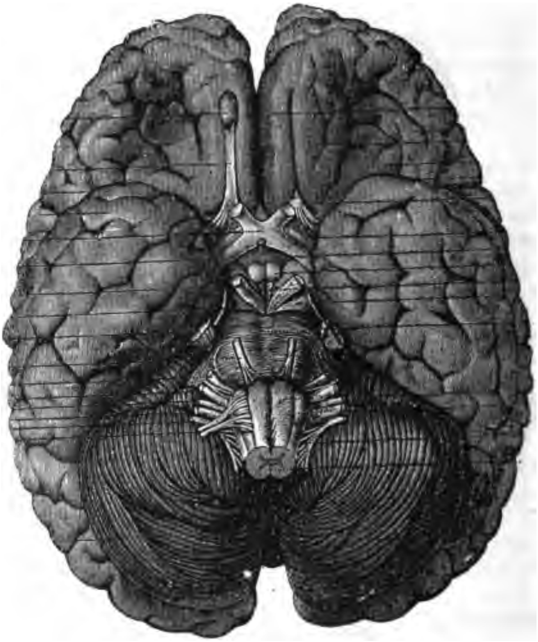


Fig. 1.—View of the inferior surface of the human brain, divested of its membranous coatings.

a nerve of motion be cut, the member which it moves will be immediately paralysed; and if a nerve of sensation be cut, the part which it connects with the brain will become insensible. Thus, for example, if the nerves of motion proceeding from the brain to the arm be divided at the shoulder, the entire arm and hand will be paralysed, the will losing all power over it. In like manner, if the nerve connecting the optical membrane of either eye be divided at any point between that membrane and the point where the nerve unites with that which proceeds from the other eye, the former eye will become blind, the sight of the latter remaining unimpaired. But if the optic nerve be divided beyond the point where the nerves from the two eyes are united, both eyes will lose the power of vision.

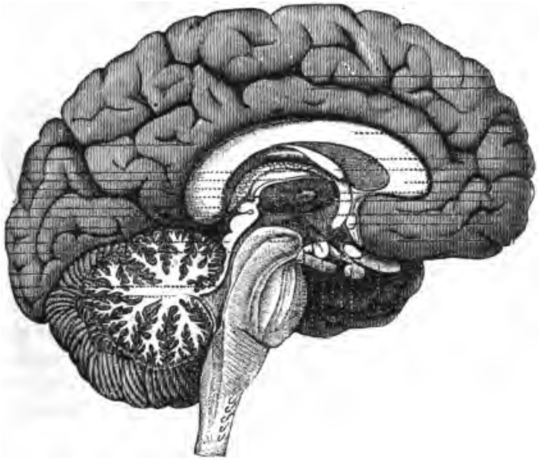


Fig. 2.—Section of the human brain, made by a vertical plane passing through the middle of the forehead.

4. The brain being the organ of intelligence, it has, as might naturally be expected, a greater development and more perfect structure in man than in the inferior animals. The *cerebral hemispheres*, as they are called, are more voluminous, and their convolutions are more prominent and numerous, and extended over a much larger region of the skull. They cover, for example, that part of the organ called the *cerebellum*, while in inferior animals they never extend over it, and in many cases have no existence at all.

The part of the brain which occupies the front of the skull in man is remarkable for the extent of its volume, and gives that peculiar elevation to the forehead and nobleness of aspect which is nowhere to be found among the inferior species.

5. The proportion which the part of the head occupied by the principal organs of sense,—those of seeing, hearing, smelling, and tasting,—bears to the part occupied by the brain and its appendages, is found to be a good general modulus of the power of the intellectual faculties; and accordingly methods have been sought by physiologists, by which this proportion can be conveniently ascertained with some degree of approximation by external indications, independently of the results of dissection. The method which has been most generally received is that proposed by Camper, an eminent Dutch naturalist, which consists in measuring what he called the *facial angle*, formed by a line, *c d*, (fig. 3) drawn through the opening of the ear and the base of the nostrils, with another line, *a b*, drawn from the most salient point of the forehead, through the front of the upper jaw. This angle will be greater or less, according to the greater or less development of the brain, especially in its anterior part.

Fig. 3.

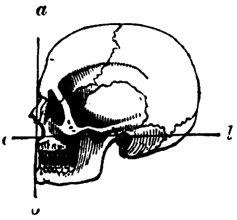


Fig. 4.

In comparing man with the inferior animals, it is found accordingly, that the facial angle exceeds those of the latter in a large proportion; and in comparing different species of animals one with another, the variation of this angle is in remarkable accordance with their several manifestations of intelligence.

6. The following are the facial angles of certain species, according to different physiological authorities:—

Man (European) (fig. 3)	85° to 90°
Ouran-Outang (fig. 4)	56° to 60°
Apes (fig. 5)	30° to 65°
Dog	35°
Ram	30°
Horse	23°

According to Professor Milne Edwards, the forehead in the case of the wild boar (fig. 6) is so falling, that it is impossible to draw a straight line from the upper jaw to the most prominent part of the skull, the latter falling considerably behind the bony projection of the nose.

Fig. 5.

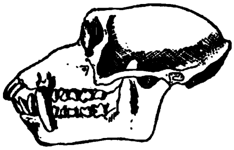
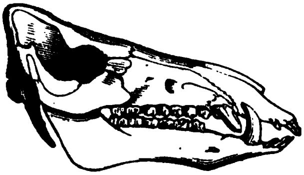


Fig. 6.

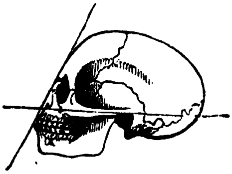


With birds and fishes the facial angle is less than with mammifers, and with reptiles, as in the crocodile (fig. 7), is often so small as to be scarcely appreciable.

Fig. 7.—Crocodile.

In comparing individuals of the human race existing in different climates and under different physical influences, the facial angle is subject to much variation. Thus, while with the European (fig. 3) it is sometimes so great as 90°, with the negro (fig. 8) it seldom exceeds 70°.

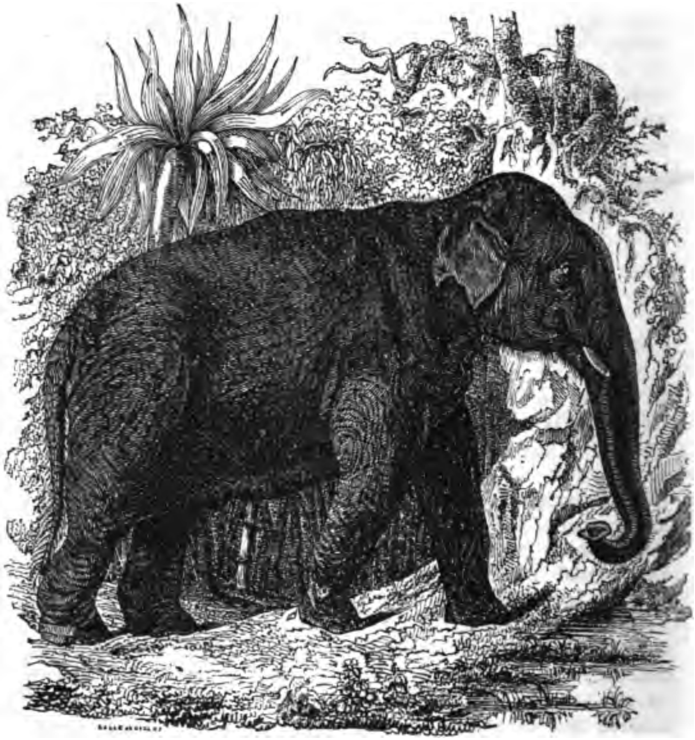
Fig. 8.



7. Although the more complete investigation of the connection of cerebral development with the extent of the intellectual faculties was reserved for modern investigators, it does not appear to have escaped the notice of the ancients, who evidently saw in the facial angle an index of intelligence. Not only do we find in their writings an erect frontal line noticed as a mark of a generous nature and an essential character of beauty, but the ancient sculptors conferred upon the figures of their heroes and their gods a facial angle much larger than is ever seen in man; and in some of the more remarkable statues which have come down to us,—the Olympian Jupiter for example,—the frontal line *b a*, fig. 3, actually inclines forwards so as to render the facial angle obtuse.

Even the most vulgar observation ascribes stupidity to a projecting mouth and nose and retiring forehead, to which the name *muzzle* is given, whether found in men or in animals. And when in exceptional cases an apparent enlargement of the facial angle is produced by a prominence of the bony arch which protects the eyes, a spurious air of intelligence is produced, which causes qualities to be ascribed to animals having this conformation, which they do not really possess. The elephant (fig. 9) and the owl (fig. 10) are examples of this.

Fig. 9.



Owing to the peculiar expression thus given, the owl, as is well known, was adopted by the ancients as the symbol of wisdom, and the Indian elephant bears an oriental name which implies the possession of a certain share of reason.

8. The brain, however, is not the only part of his organism, to which man owes his great superiority; the conformation of his members, combined with his intellectual powers, gives him a

dominion over the inferior species, which he never could obtain by his natural strength or swiftness.

Like that of the superior classes of Mammifers generally, the human body is supplied with four members; the superior, or arms and hands, and the inferior, or legs and feet. It is found in the works of nature, as in those of art, that the more extensively the principle of the division of labour is carried out, the greater will be the perfection of the instruments. A tool or a machine, which attains two purposes, attains neither of them so perfectly as would two tools or machines especially adapted to the execution of each. Now we find, on comparing man with the inferior animals, that he supplies a solitary example of the rigorous application of the principle of the division of labour in the functions of his members. The necessities of its well-being require that the creature should be supplied with members to seize and members to pursue the objects of its nutrition. Hence arises the necessity for members of prehension and members of locomotion. In some of the inferior animals, as, for example, certain quadrupeds, the four members are exclusively locomotive, the act of prehension being confined to the mouth. In others, however, all the four members, besides fulfilling the functions of locomotion, are more or less prehensile, thus serving a double purpose, and therefore, according to the principle explained above, serving it by comparison less perfectly. In some, the prehensile functions of the four members prevailing over their locomotive functions, naturalists have given them the name of *quadrumana*, or four-handed, in contradistinction to that of quadrupeds, or four-footed, given to those species whose members are more exclusively locomotive.

Fig. 10.

9. In man alone are found at once members which are exclusively prehensile, and others exclusively locomotive.

10. The superior members are disposed in a manner most favourable for prehension and touch. By the peculiar mechanism of the shoulder-joint, the arm can be directed with nearly equal facility upwards, downwards, forwards, and backwards. The fore-arm at the same time being hinged upon the elbow, and the hand upon the wrist, a still more varied play is given to the hand, the immediate instrument of prehension. But even with this

variety of motion and inflection, something would still be wanting. The chief seat of the sensibility of touch is the palm of the hand and the palmar sides of the fingers; and the mechanism of the hand is so contrived as to accommodate itself to the play of this sensibility. The thumb is mounted so as to face the fingers, and the articulations of both are such as to enable them to be inflected towards each other, and towards the palm, so that when an object is embraced or grasped by the fingers, all the part of the hand possessing most sensibility of touch is brought into contact with it. If we grasp the hand of a friend or a beloved relative, the palms come into contact, and we are conscious of a mutual sensation conveyed through the nervous system. If, while the mechanism of the hand remains the same, the nerves which now overspread the palm and the palmar sides of the fingers were spread over the back of the hand, all this sensibility would cease.

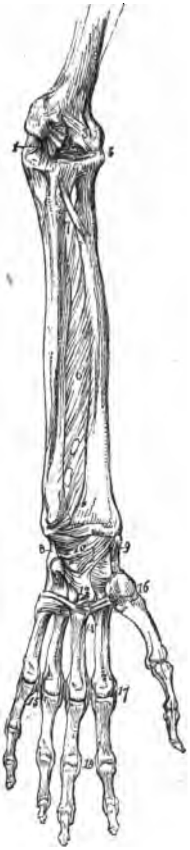
It is obviously essential that the palm of the hand, which is thus its prehensive side, should be capable of being turned in all directions, so as to present itself to the objects to be grasped or touched. But the hinge joints of the wrist and elbow would only enable the palm to be inflected inwards towards the hollow of the arm.

It is true that the rotatory motion which can be given to the arm upon the shoulder would vary the play of the palm, but the motion would still be imperfect for the purposes of prehension and touch. An expedient is, therefore, provided, which may be fairly said to confer upon the hand the utmost perfection as an organ of prehension. This expedient consists of a simple and beautiful mechanical arrangement in the structure of the fore arm, which is composed between the elbow and wrist, not of one, but of two bones, of nearly equal length, placed side by side. One of these, called the *ulna*, is articulated with the upper bone of the arm at the elbow by a hinge joint; the other, called the *radius*, is articulated to the hand at the wrist, with a like hinge motion. But the radius having the hand thus appended to it is so arranged that it can revolve round the ulna, carrying the hand with it, thus having the faculty of presenting the palm in any desired direction without changing the general position of the arm.

11. In fig. 11, the bones of the arm and hand are represented; the ulna, hinged upon the elbow, being on the left, and the radius, with the hand hinged upon it at the wrist, being on the right. The two bones are tied together by intermediate ligaments (6, 7), the ligament by which the hand is tied to the radius appearing at 10. The palm of the hand and the hollow of the elbow are supposed to be presented to the observer.

When to all these conditions it is added that the successive bones of the fingers gradually decrease in length; that they are articulated with a succession of hinge joints; that they are moved independently, one of another, by a series of muscles acted upon by nerves which are under the complete dominion of the will, the admirable perfection of the organ of prehension and touch may be in some degree appreciated.

Fig. 11.



12. When the movements of the arm, hand, and fingers, are considered collectively, it may be stated, without exaggeration, that in directing the fingers to any object of touch, a hundred muscles are brought into operation, whose contractile power is excited by thousands of nervous filaments, each of which is under the absolute dominion of the will, each action of volition requiring a corresponding intellectual exertion. How wondrous this machinery intellectual, physiological, and mechanical, must be, the least reflection upon the manual exercises which are daily performed, especially in civilised and polished life, will render manifest. When a performer, for example, executes upon the piano-forte one of the complicated compositions of the modern composers for that instrument, as many as ten thousand notes must be produced by the application of the fingers to the keys. The longest of these pieces is executed in about 15 minutes, or, in round numbers, 1000 seconds, so that the notes must be produced at the rate of 10 per second, and as each note requires a separate dictate of the will, and each dictate of the will a separate act of the mind, we arrive at the surprising conclusion that these mental acts are performed in this particular case at the rate of 10 per second. Nor can it be said that habit enables the fingers to move mechanically while the mind is passive, and that the facility given by repetition supersedes mental action; for artists are found so expert as to execute such pieces at sight, never having previously studied them.

13. The lower members are as eminently fitted for the purposes of support and locomotion as are the superior for prehension. Attached to the hip bones or pelvis, at the external corners, they are so articulated as to have a certain play forward, backward,

and laterally, sufficient for the purpose of locomotion, yet not too great for stability.

While the arm at the shoulder plays in an extremely shallow socket, so as to give it all that vast range of motion which is necessary in an organ of prehension, but would be altogether incompatible with one of sustentation, the thigh bone is articulated at the hip in a deep spherical socket, which looks obliquely downwards, and which rests upon the convex head of the bone with sufficient firmness and solidity to afford a secure support to the incumbent weight of the trunk, the upper members, and the head.

14. The leg is articulated to the thigh at the knee by a hinge joint, which enables it to be inflected backwards, so as to accommodate itself to a progressive motion. Unlike the hand, the foot has no rotatory motion on the leg; the two bones composing which, firmly united together, confine between them the upper bone of the foot, forming the ankles at either side of it. The foot thus moves with a hinge motion on the ankle joint, projecting backwards at the heel, and still further forward in the direction of the toes, so as to supply a large basis for the support of the body.

The toes, unlike the thumb and fingers, are totally incapable of prehension; the great toe, which corresponds to the thumb, instead of facing the others, is placed in juxtaposition with them, and they cannot therefore be brought together so as to form, like the fingers and thumb, a sort of pincers.

The sole of the foot corresponds to the palm, and the instep to the back, of the hand. The bones of the latter, extending obliquely from the bend of the ankle joint to the commencement of the toes, form an elastic arch, by which the blood-vessels, nerves, and muscles of the foot are protected from the pressure of the weight of the body, which would otherwise crush them. The fleshy mass formed by the muscles and fat placed upon the sole constitutes a cushion or buffer, which softens the collision which must otherwise take place each time that the foot comes to the ground, with the whole weight of the body upon it.

15. Everything in the mechanical structure of the body conspires to prove that man was made to stand erect; and with this erect position are associated numerous consequences connected with his superiority over other species. His feet are formed with a base which is large in proportion to his body, so that the centre of gravity can be easily kept vertically over it, a condition which is essential to his stability. The legs, in their natural position, are placed at right angles to the soles of the feet, and are therefore vertical when the latter are horizontal. The centre of gravity of the trunk is at some distance in front of the spinal column, and would therefore have a tendency to incline forward, so that the

body would take the position of that of a quadruped, in which the spinal column would be horizontal, the upper part of the trunk being supported by the arms, the hands performing the duties of fore-feet. But this is prevented by the establishment along the whole extent of the back of several layers of powerful muscles, which tie the vertebræ together, two and two, three and three, four and four, and so on. The tone of these muscles is such, that their normal tension produces a force which equilibrates with the weight of the trunk acting at its centre of gravity in front of the spine. These muscles have a power of contraction and relaxation within certain limits, by which the body can be inclined backwards or forwards, more or less. The head is mounted upon the summit of the vertebral column, forming as it were its capital, in a manner obviously adapted for the vertical position. Like the trunk, its centre of gravity is a little in front of the summit to the spinal column, and therefore it would have a tendency to incline forwards, but this as before is resisted by muscles of adequate power placed on the back of the neck.

Nothing more manifestly indicates the intention of nature that man should stand erect, than the position of his face and the direction of his optic axes. In the erect position his face looks forwards, and the optic axes are horizontal. But if he were to assume the prone position, supported by his four members like a quadruped, the optic axes would be directed downwards, and, except by a strained effort of the neck, he could not see before him. To this it may be added, that the knee joint being so constructed that the leg can only be deflected backwards on the thigh, would render the legs utterly unfitted to be members of support and locomotion in the prone position, since in that case the point of support would be, not the feet, but the knees. Now, independently of the consideration that in this case the legs and feet would not only become useless, but would be an impediment to every act of locomotion, the shortness of the thigh would inconveniently limit the power of progression, the thin integuments covering the knee-pan would soon be destroyed by the pressure upon it, and the knee-pan itself, a loose and detached bone, would be displaced, and the members totally disabled.

It would not be worth while to insist upon these particulars, were it not that some authors, impelled doubtless by the love of paradox, have maintained that the prone position is natural to man, and the erect position the result of education.

16. Man, then, alone presents the characters of a *bimanous* and *bipedous* animal. The various species of apes, who approach so close to him in some respects, differ from him essentially in their members, their inferior or posterior members having as much the

character of hands as of feet, and their anterior members as much the character of feet as of hands.

In fig. 12 is represented the species of ape called the chimpanzee, using the anterior member as a prehensile organ. In fig. 13 another species of quadrumana is shown, where the conformation of all the four feet closely corresponds with that of the human hand, but all the four are used for support and locomotion.


Fig. 12.—The Chimpanzee.


Fig. 13.—The Mandrill.

It is evident that the mode of locomotion to which the mixed character of the hand and foot found in the quadrumana is best adapted, is that of climbing, to which accordingly the monkey tribes are more especially addicted, often carrying their young clinging round their bodies as they mount.

In fig. 14, a monkey called the *maki*, a species of lemur, is represented in one of its habitual attitudes, carrying its young.

17. The double purpose of prehension and locomotion assigned to the members of the quadrumana, and their habitual exercise of climbing in pursuit of their food and for protection from their enemies, renders the occasional aid of another organ of prehension necessary; such an organ is accordingly supplied them in the tail. In fig. 15 is represented the White-throated Monkey thus exercising this prehensile action. The same action is common with the species called the *Coaita*, or Spider-Monkey, so named from the extraordinary length of its extremities, and from its motions. "The tail," says Sir Charles Bell, "answers all the purposes of a hand, and the animal throws itself about from branch to branch, sometimes swinging by the foot, sometimes by the fore extremity,

but oftener and with greater reach by the tail. The prehensile part of the tail is covered with skin only, forming an organ of touch as discriminating as the proper extremities. The *Caraya*, or Black Howling Monkey of Cumana, when shot, is found suspended by its tail round a branch. Naturalists have been so struck with this property of the tail of the *Ateles*, that they have compared it to the proboscis of the Elephant, and have assured us that they fish with their tail.

Fig. 14.—The Maki.

"The most interesting use of the tail is seen in the opossum. The young of that animal mount upon her back, and entwine their tails round their mother's tail, by which they sit secure while she escapes from her enemies." *

It will be observed that the young one, represented in fig. 14, also uses its tail as an organ of prehension, holding itself upon the body of its mother by twining the tail round her.

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* Bell, On the Hand, p. 20.

18. But of all the organs to which man owes his superiority, that of voice is incontestably the most important. He alone, among all created beings, is endowed with the power of producing articulate sounds in infinite variety, and applying them to the expression of his thoughts, sentiments, and feelings. By this power he is enabled to communicate with his kind, to interchange with them the expressions of kindness and affection, and to impart and receive knowledge and information. Great as this power is, it is augmented in a manifold proportion by the device of expressing oral sounds by written or printed characters. By this expedient oral language becomes visible, and is, so to speak, perpetuated; the discourse which is spoken or listened to, however impressive may be the eloquence of the speaker, and however profound the attention of the hearer, may, and generally does, soon fade from the memory, but language printed or written is permanent,

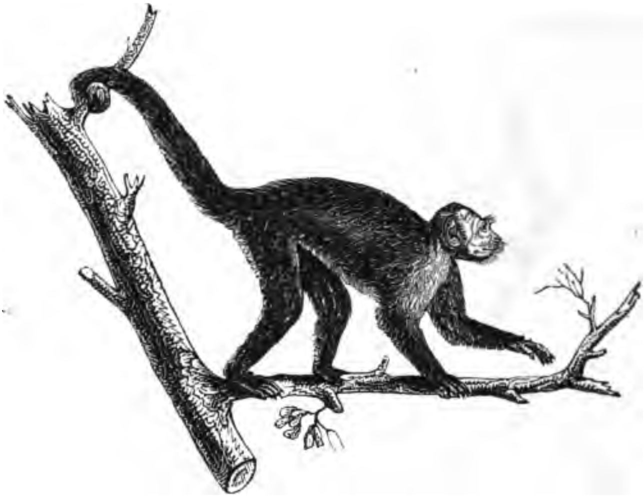


Fig. 15.—The White-Throated Monkey.

Litera scripta manet,

and may be referred to again and again until the reader renders it his own.

The printed book can be handed down and reproduced indefinitely from age to age, and those of one generation are thus enabled to listen to the precepts and imbibe the counsels of the wisest and most virtuous of former times.

Fig. 21.—MONGOL.

COMMON THINGS.

MAN.

CHAPTER II.

19. Physical feebleness of man.—20. His helpless infancy.—21. His great power nevertheless.—22. Man gregarious.—23. His dentile apparatus.—24. Why nevertheless he uses animal food.—25. His migratory power and distribution over the globe.—26. View of his progress from the cradle to the grave.—27. Births.—28. Cases of two and three at a birth.—29. Births more prevalent at certain seasons.—30. Proportion of the sexes born.—31. Proportion in the case of illegitimates.—32. Chances of life more favourable for females.—33. Organs of sense in infancy—the eye.—34. The voice.—35. The bones.—36. Instinct in the infant.—37. Terror of falling.—38. Milk teeth.—39. Permanent teeth.—40. Their periods of emergence.—41. The average height of men.—42. Giants and dwarfs.—43. Average height of women.—44. The influence of race.—45. Influence of climate.—46. Hygienic conditions.—47. Their effects shown by conscription in France.—48. Rate of growth from infancy to maturity.—49. Progressive increase of bulk.—50. Organic changes at puberty.—51. Organic changes in the bones. 52. The muscles.—53. Examples of longevity.—54. Great mortality in infancy.

19. MAN thus singularly favoured by the possession of reason, and by the address and precision of which the motions of his

members, and more especially those of the hand, are susceptible, is, nevertheless, in some of his physical attributes, immeasurably inferior to other animals which correspond with him nearly in size. He is neither swift of foot to pursue his prey or fly from his enemies; nor is he supplied with any natural weapons of attack or defence, such as those which are found among the numerous classes of animals around him. He is not only feeble and defenceless, but Nature has refused to provide him with those means of protection from the inclemency of the elements, which she has so beneficently supplied to those who hold a lower place in the chain of organised beings. He has neither the fur of the beast, nor the feathers of the bird, to protect him from the rigours of temperature, and yet his body is covered with a skin and integuments abounding in nerves, which render it ten thousand times more sensitive than the skin of any of these creatures which Nature has so carefully and tenderly protected.

20. In coming into the world, he is more helpless and delicate than the young of any other creature, and continues for a much longer period dependent, not for his well-being only, but for his very existence, upon the assiduous and never-ceasing solicitude and tenderness of his parents.

21. Yet this creature, thus naturally poor, feeble, naked, helpless, and defenceless, is the lord and master of the material world. By him the strongest is subdued, the fiercest tamed, the swiftest overtaken. He cannot rise into the air, nevertheless he arrests its inhabitants in their flight and brings them to his feet. He cannot descend into the waters, nevertheless he calls forth from the chambers of the deep their tenants, for the supply of his wants and the gratification of his appetites. His body is unprotected by any natural covering, but the beasts of the forest and the birds of the air are compelled to surrender for his use their fur, and their plumage. Innumerable textile plants, which in their natural state would be unavailing, are adapted by his art to supply the materials by which clothing for his body can be made in unbounded quantity. Unable to endure the vicissitudes of temperature and climate, the earth itself is compelled to surrender its bowels, and to supply inexhaustible quantities of fuel, by which artificial heat is produced to moderate the rigours of cold and equalise temperature. He is not swift of foot to pursue or to fly, but he tames for his use the swiftest of subordinate creatures, which with the most absolute obedience transport him where he wills. Not satisfied even with this, his inventive powers have created engines of transport which carry him over the face of the waters, in spite of opposing wind and tide, and over the surface of the land, with a speed which

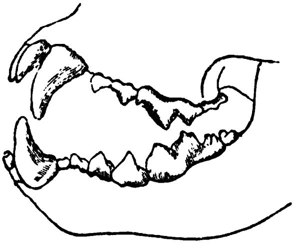
exceeds the flight of the swiftest bird and equals the rapidity of the tempest.

So far, then, from having reason to repine at his helpless and defenceless organisation, he is indebted to those apparent defects for the greatest of his attainments; for it is certain, that if he had possessed natural organs of defence, attack, and locomotion, and natural protection for his body at all analogous to those which have been provided so generally for the inferior species, he would have lost that strong stimulus which has urged him on to such stupendous and almost incredible achievements. Nor is this observation novel. At a much earlier epoch in the progress of the human race, and ages before the great discoveries had been made which will render for ever memorable the last hundred years, Galen observed, that if man had possessed the natural clothing and defence of the brute, he would never have been an artificer, nor protected himself with a cuirass, nor fabricated the sword or spear, nor invented the bridle, nor mounted a horse, nor hunted the beast. Neither would he have followed the arts of peace, nor constructed the pipe and the lyre, nor erected houses or palaces, nor temples to the gods; nor would he have made laws, nor invented letters by which he would hold communion with the wise of antiquity, conversing at one time with Plato, at another with Aristotle, and at another with Hippocrates.

22. The possession of the faculty of language necessarily infers the instinct of sociability, and man cannot live alone. He seeks the society of his kind, and belongs to the class which naturalists call *gregarious.* The advantages derived from this habit of association are infinite; without it, indeed, man, instead of being as he is, the monarch of nature, would be amongst the most miserable of animals, and would assuredly soon disappear from the earth. But by association every individual strengthens and supports others, and is strengthened and supported by them. Each cultivating some special faculty or power in a higher degree than his fellows, renders it serviceable to them, and receives in return equivalent services from those who have cultivated other powers in which he is deficient; and thus comes into play that vast principle of material production and social felicity known as the division of labour.

Like all other gregarious animals, man is naturally frugivorous, or made to live on fruit and vegetables. This is a conclusion not resting solely upon the analogy observable between man and other gregarious species, but supported by the characters of his organs of nutrition. The teeth of carnivorous species (fig. 16) are peculiarly formed for tearing and masticating the flesh which constitutes their proper food. The canine teeth are largely developed, sharp and curved; and the incisors partake of the canine character. The teeth which occupy the place of molars, edged and sharp, close side by side like the blades of scissors. The dentile apparatus is thus adapted to tear and cut the flesh before it passes into the stomach. The teeth, on the contrary, of frugivorous animals consist of incisors and molars; the canine teeth existing, but so little developed as to have no functions different from those of incisors. The molars of the two jaws, nearly flat at their ends, come into direct contact and superposition like two millstones, and the jaws, by a small lateral motion, have the power not only of bruising but of grinding the food between them. These operations are all that is necessary and sufficient for vegetable, but would be altogether inapplicable to animal food.

Fig. 16.



23. Every one will recognise in the dentile apparatus last described the form and structure of the human teeth; and so far as they are an index of the food adapted to them, it is plain that man is frugivorous. But the same conclusion is further supported by an examination of the digestive apparatus.

In carnivorous species, the intestine through which the food passes is generally short, its length not exceeding three or four times that of the body, while in the herbivorous species it is usually ten or twelve, and sometimes (as in the sheep, for example) twenty-eight times the length of the body. In accordance with this principle, we find that the human intestine, like the teeth, is suited to vegetable aliment, having a length bearing a proportion to that of the body, which is analogous to the internal structure of other frugivorous species.

24. How then, it may be asked, has it happened that man, instead of being exclusively frugivorous, is, in fact, omnivorous, nourishing himself indifferently with vegetable and animal aliment? The answer is obviously, that he cannot be nourished by animal aliment, unless it be previously prepared by fire. In a word, flesh, to be fit for human food, must be cooked.

25. One of the physical peculiarities which distinguishes man from other members of the animal kingdom, is the facility with which his organisation adapts itself to differences of climate, and this is one of the marks which appear to confirm his destiny to rule over the whole surface of the globe. Placed originally by his Maker in a single region, his race has multiplied and diffused

itself, manifesting a constant tendency to emigration, and being deterred neither by the rigours of the pole, nor the scorching sun of the tropics, it has overspread the globe. According to statistical estimates, which are considered as exact as such calculations can be, it was ascertained that, at the epoch of 1840, the total population of the globe amounted to about 737,000000, which were distributed in the following proportions, the number to every square league, taking the length of a league as the 25th part of a degree, being given in the second column :—

	Population.	Per Sq. League.
Europe	227,700000	472
Asia	390,000000	184
Africa	60,000000	40
America	39,000000	20
Oceania, including the isles of the Pacific Ocean, &c.	20,000000	37

The density of the population, indicated in the last column, depends more on civilisation and wealth than on climate. Thus, it is computed that the number of inhabitants per square league in the different states of Europe, are as follows :—

United Kingdom	1480
France	1200
Prussia	895
Russia	202

26. Having taken this rapid view of the physical organisation and condition of the human race, let us trace the progress of the animal Man from the cradle to the grave.

27. In general, man comes into the world singly, or one at a birth. In certain exceptional cases, two are born, and called twins. The cases in which three or more at a birth are produced are so extremely rare as not to have received in any language, that we are aware of, a distinct appellation.

28. It appears by statistical returns, that, upon an average, one case of twins occurs in 90 births; and that three at a birth has occurred only once in 30000 cases.

29. Another circumstance, in which the human race is distinguished from inferior animals, is the independence of the phenomenon of birth on the season of the year. Animals generally produce their young at that season which is most favourable for their development. Children are born at all seasons. Nevertheless, in comparing the number of births with the course of the

seasons, it is found to be variable, and that its variation has a marked and well-ascertained relation to the course of the seasons. It is found generally in the temperate climates, that births are more numerous in the three winter, and least so in the three summer months. In approaching the colder climates, the epochs of the maximum and minimum numbers are later, and in approaching the warmer climates earlier.

30. The number of children which come into the world is not equally shared between the sexes, the male always predominating.

This fact has been established in all countries where statistical registers have been kept; and it is remarkable, that although the numerical proportion between the sexes is subject to some variation from year to year, its mean amount in each country is nearly invariable, though different in one country as compared with another. Thus, on comparing the numbers of male and female children baptised in England and Wales during the first half of the present century, it is found that the number of males invariably exceeded the number of females in a proportion, varying from year to year, from 25 to 50 per 1000; the mean result taken for the whole period showing, that for every thousand girls born, there were one thousand and forty boys.

In France, according to returns extended over 36 years, terminating in 1852, it appears, that for every thousand girls there were one thousand and sixty-one boys born. Thus the preponderance of male births in France exceeds that in England in the proportion of a little more than 6 to 4.

By returns obtained from other countries where accurate statistics are kept, it has been found that the preponderance of male births is intermediate between those of England and France, the number of males being 1050 for every 1000 females.

31. A very remarkable fact, indicating some undiscovered physiological law, has been developed by the analysis of the returns of the registrations of births obtained from France and other countries where the most exact statistical records are kept. It has been found generally, that in that particular class of children, to which foundlings for the most part belong, the preponderance of male births is considerably less than in the case of marriage-born children. Such a circumstance would naturally enough be regarded as merely accidental, if it were not found to prevail invariably, at all epochs in all countries where registers are kept with sufficient precision to test the fact, and in all provinces of the same country. Thus, for example, while in France there are 1060 marriage-born boys for 1000 girls, there are only 1040 boys of the other class for the same number of girls; and

this proportion has been found to be maintained from year to year, and equally in different departments.

From a comparison of the births in different departments of France, north and south, it has been found that the proportion of the sexes born is not affected by climate.

32. It must not be supposed, however, that this ratio between the sexes continues through life. The chances of life being more favourable on the whole to females than to males, the excess given to the latter at birth is equalised before the middle age; and at more advanced ages, the balance turns the other way, and the females predominate.

33. In coming into the world, the infant can open the eyes, but physiologists consider that it has no sense of vision, and that it is only at the end of some weeks that it begins to be sensible of visible objects. After this, it directs its looks to objects which are most brilliantly illuminated, or which are characterised by the most vivid colours. It then, by slow degrees, begins to distinguish objects around it, but it has been ascertained that a considerable time elapses before it has any idea of distances or magnitudes.

Indeed, this is quite consistent with effects which have been found to result from surgical operations in which sight has been restored to persons blind from infancy. In such cases, it has been stated that the subject of the operation, when first enabled to see, imagined that all the objects which he beheld were in immediate contact with his eyes, and had not the least idea of their relative distances, nor any other notions of their magnitudes or forms than such as were afforded by their profiles. Every object, in short, appeared as a coloured silhouette in close contiguity with the organs of vision.

34. The other organs equally undergo a progressive improvement by exercise. During five or six months the infant makes no other vocal sound than inarticulate cries. It begins gradually to be sensible of pleasurable emotions from the contemplation of external objects, which are expressed by its smiles. The cries gradually assume the tone and character of the voice, and are accompanied by incipient efforts at articulation, and towards the close of the first year the more simple monosyllabic words are pronounced.

35. The bones, which at the time of birth consist to a great extent of cartilage or gristle, and have no strength sufficient to support the body, receive, in the process of nutrition, a gradual accession of the earthy constituent called the phosphate of lime, which gives them hardness. Contemporaneously with this increase of strength in the bones, there is a proportionate growth

and increase of strength in the muscles which move them, and about the close of the first year this strength bears such a relation to the weight of the body, that the child is enabled to support itself on its legs, and by gradual practice acquires the ability to walk.

36. It is generally assumed that man is distinguished from the inferior animals by the substitution of reason for instinct, and in this way it is explained how the young of other animals manifest at the moment of birth the possession of powers and faculties, which, in the case of the young of the human race, are acquired only by long practice and slow degrees. It is therefore contended, that while the young of the lower animals are governed exclusively by instinct, the young of man is as exclusively governed by reason, the conclusions of which are based upon experience. The acts prompted by instinct are performed as perfectly at first as at last, and undergo no progressive improvement; while, on the contrary, the dictates of reason being based upon experience, cannot be issued by the mind until the results of that experience, which are their only data, have been developed. It has, therefore, been argued, that the helplessness of the infant, and the slow and gradual progress of the exercise of its senses and members, must be explained by the total absence of instinct. This conclusion, however, it seems cannot be admitted in its absolute sense, and observation and experience show that it requires considerable qualification. Many eminent physiologists impugn it, and Sir Charles Bell has even expressed a doubt whether the actions of the body, if not first instinctive or prompted by innate sensibilities, would ever be exercised under the exclusive influence of reason. The sensibilities and motions of the lips and tongue are, according to him, perfect at birth; and the fear of falling is manifested by the infant long before the results of experience can suggest it. The hand, destined to become the instrument not only for the improvement of the senses, but for the development of the mental faculties, is absolutely powerless in the infant. Although capable of expressing pain, it is unconscious of the part injured. But the lips and tongue immediately betray their sensibility. Later, the infant puts its fingers into its mouth to suck them, and so soon as they are capable of grasping, whatever they lay hold of is carried to the mouth.

"The first office of the hand, then, is to exercise the sensibility of the mouth, and the infant as certainly questions the reality of things by that test, as does the dog by its acute sense of smelling. In the infant the sense of the lips and tongue is resigned in favour of that of vision, only when the exercise of the eye has improved and offers greater attraction. The hand acquires the sense of touch very slowly, and many ineffectual efforts may be observed in the arms and fingers of the child, before it can estimate the direction or distance of objects. Gradually the length of the arm, and the extent of its motions, become the measure of distance, of form, of relation, and perhaps of time.

37. "Next in importance to the sensibility of the mouth, we may consider that sense which is early exhibited in the infant, the terror of falling.

"The nurse will tell us that the infant lies composed in her arms, while she carries it upstairs, but that it is agitated when she carries it down. If an infant be laid upon the arms and dandled up and down, its body and limbs will be at rest when it is raised, but in descending it will struggle and make efforts. Here is the indication of a sense, an innate feeling of danger, and we may perceive its influence when the child first attempts to stand or run. When set upon its feet, the nurse's arms forming a hoop around it, without touching it, the child slowly learns to balance itself and stand; but under a considerable apprehension. It will only try to stand at such a distance from the nurse's knee, that if it should fall, it can throw itself for protection into her lap. In these, its first attempts to use its muscular frame, it is directed by a fear which cannot as yet be attributed to experience. By degrees it acquires the knowledge of the measure of its arm, the relative distance to which it can reach, and the power of its muscles. Children are, therefore, cowardly by instinct; they show an apprehension of falling, and we may trace the gradual efforts which they make under the guidance of this sense of danger to perfect the muscular sense. We thus perceive how instinct and reason are combined in early infancy; how necessary the first is to existence; how it soon becomes subservient to reason, and how it eventually yields to the progress of reason, until obscured so much that we can hardly discern its influence."*

38. At the moment of birth, twenty teeth already formed and ossified are deposited, ten in the lower and ten in the upper jaw, but are completely covered by the gums. The mouth is thus constituted exclusively for application to the mother's breast and for the suction of milk from it, and the stomach and intestines are organised in accordance with this for the due digestion of that aliment. The constituents of the healthy milk of woman are the same as those of the body of the child, and enter into its composition in a corresponding proportion. By the process of digestion, they are distributed among the several organs of the child's body,

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* Bell, On the Hand, p. 233.

each passing to that for whose sustenance and growth it is fitted. At the age of from six to ten months, the first teeth penetrate through the gum, and towards the end of the second year the entire number have appeared. These twenty teeth are classified according to their peculiar forms, as incisors, canines, and molars. The incisors are chiselled, the canines pointed, and the molars presenting a broad and rough summit. When the mouth is closed the molars of the upper jaw corresponding in position with those of the lower, rest upon them. But the lower incisors and canines lie within the edges of the upper ones. In each of the jaws, there is, however, space for sixteen teeth, and consequently three places at each side remain unoccupied.

The relative arrangement of this set of teeth is shown in fig. 17, where the incisors are indicated by I; the canines by C, and the molars by M; the unoccupied spaces being marked ″

The first teeth which break through the jaw, are the middle

Fig. 17.

incisors I^1 I^1; these are succeeded in regular succession by the lateral incisors I^2 I^2, the canines C C, and the molars M^1 M^1 and M^2 M^2.

39. This first set of teeth are called the milk teeth, because of their emergence from the gums at the time when the aliment of the child is changed from the milk of the mother to other forms of food. Towards the seventh year, these teeth begin to be pushed out of the jaw by another set which have been growing beneath them. The incisors and canines are pushed out by another set perfectly similar in form and name, which take their places. The molars are in like manner extruded by four teeth in each jaw called *bicuspids*, having an intermediate character between incisors and molars.

Later still, four molars issue from the gum in each jaw, two at each side, occupying the first two of the three vacant places marked " in fig. 17, and at a still more advanced age, two other molars issue from each jaw, filling the last vacant place marked " in the fig. 17.

Thus, a set of sixteen permanent teeth is established in each jaw (fig. 18). The last four molars, which emerge at a period of life much later than the others, have been for that reason vulgarly called wisdom teeth.

Fig. 18.

40. The periods of the successive emergence of the permanent teeth are, according to Cartwright, as follows :—

	AGE.
Middle incisors of lower jaw (I^1), and first molars (M^1)	5 to 7
Middle incisors of upper jaw	6 to 8
Lateral incisors (I^2)	7 to 9
First bicuspids (B^1)	8 to 10
Canines (C)	9 to 12
Second bicuspids (B^2)	10 to 12
Second molars (M^2)	12 to 14
Third molars (M^3) (wisdom teeth) . . .	17 to 25

41. The mean height of man is about 5 feet 6 inches, but is subject to great variation, not only in the case of individual compared with individual, but nation with nation, and race with race. Some of the savage tribes of Patagonia, and the inhabitants of the Navigator and Caribbean islands, are remarkable for their elevated stature, their average height varying from 6 feet to 6 feet 3 inches.

On the contrary, the Esquimaux and Bushmen have an average height not exceeding 4 feet 3 inches.

42. If, instead of comparing people with people, individual be compared with individual, still greater departures from the average standard are found. Thus, we have seen giants which have attained the enormous height of 9 feet 6 inches, and, on the other hand, dwarfs whose height did not exceed 2 feet.

43. Among persons of average height, women are about a sixteenth less tall than men; but among people whose average height is less than the common standard, such as the Esquimaux and Bushmen, there is less inequality between the sexes; while in those of greater average height, such as the Patagonians, the inequality is greater. In fact the sexual inequality appears to vary nearly in the ratio of the mean stature.

The inequalities of mean stature observed in comparing people with people, depend partly upon race, or partly on the physical conditions with which they are surrounded.

44. The influence of race is more especially apparent when different people, inhabiting the same country, with similar manners, and subject to like climatological influences, are compared together. In Patagonia, for example, where certain nomadic tribes of very elevated stature prevail, there are others whose stature has about the ordinary standard, and at a little distance in the Tierra del Fuego, people of low stature prevail. The people of greatest mean stature are found chiefly in the southern hemisphere, either on the South American continent, or in the several archipelagos of the Southern Ocean.

45. Although people of low average stature are found within the tropics, and in places near the Cape of Good Hope, where the climate is sufficiently temperate, it cannot be doubted that a rigorous climate is unfavourable to the development of the human form, for in high latitudes in both hemispheres the inhabitants are invariably characterised by diminutive stature.

Moderate cold, on the contrary, is favourable to the corporeal development. In France and other parts of Europe, where the climate is mild, the average stature is less than in the colder parts of Europe, such as Sweden, Finland, and even Saxony and the Ukraine.

46. Temperature, however, exercises on the whole less influence upon bodily development than the general hygienic conditions of a people, and it may be received as a general principle that the mean stature will be so much the more elevated, and the complete growth sooner accomplished, other things being the same, as the country inhabited by a people is more fertile and abundant, and the sufferings and privations sustained during youth less consider-

able. Innumerable proofs of this truth may be found by comparing nation with nation. But it may be rendered still more strikingly apparent by comparing together the inhabitants of different provinces of the same country, or even those of different divisions of a large city.

47. It is well known that, by the laws of France, the army is recruited by conscription, in carrying out which means are incidentally supplied of ascertaining with great precision the sanitary condition and bodily development of the population. The capital of that country, containing upwards of a million of inhabitants, is distributed into quarters, called arrondissements, which differ one from another in relation to wealth or poverty, even more than do the various quarters of London. Thus while in the north-western arrondissements misery and want are rare, in some others, such as the 6th, the 11th, and the 12th, they prevail to a great extent. In the former, 45 in every 100 conscripts are found unfit for military service, chiefly because of insufficient stature, and the remaining 55 have an average height 5 feet 6½ inches, while in the latter quarters, where poverty is more prevalent, 52 in a 100 are rejected, and the remaining 48 have an average height of only 5 feet 6 inches.

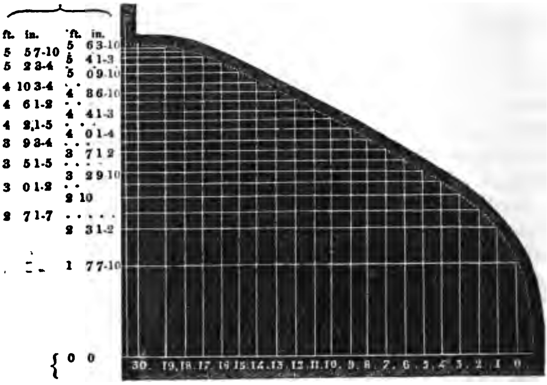
48. Statistical returns sufficiently exact and regular to indicate the average progressive growth of the human body, though rare, are not unattainable. In Belgium, for example, where the average stature is somewhat greater than in France, it has been found that the average height of new-born infants is 19⅜ inches, and at the end of the first year it is increased to 27½ inches.

In the second year the growth is less rapid, and in every succeeding year becomes less and less so, until the full growth has been attained. The annexed diagram, however, fig. 19, will convey a more exact notion of the mean progressive growth than could any mere numerical statements. It is due to M. Quetelet, to whose physical and statistical researches science is otherwise so largely indebted. The successive years in the age of an individual, from the moment of birth to the age of thirty, are indicated in the horizontal line, and the corresponding average heights in the vertical column.

It appears, therefore, that at the moment of birth the infant has a stature equal to about 2-7ths, and at three years old, about half of its ultimate height.

At the moment of birth, the average height of boys exceeds that of girls by about the 20th of an inch, and this difference increases with their growth. Nevertheless, the results obtained by M. Quetelet must be received merely as first approximations ; the observations and inductions necessary to establish general and certain laws being much more numerous than any which statistical records have yet supplied. It may, however, be assumed that in extreme climates, whether hot or cold, the body arrives at its full height sooner than in temperate climates; in towns sooner than in the country, and in plains sooner than in mountainous districts.

Fig 19.



49. The development of the body in bulk is slower than its growth in height. A new-born infant has upon an average about a twentieth of the weight which it will acquire upon attaining its greatest development, which takes place in general for men at 40 and for women at 50.

During the first year after birth, the increment of weight is about $\frac{1}{10}$ of all that it will receive during its subsequent existence; and the increase of weight received from the 15th to the 20th year is even greater than that which is acquired in the first five years.

50. On arriving nearly at the limit of his stature, the male passing from youth to manhood undergoes several organic changes. His bones having acquired a larger proportion of the earthy constituent, have increased strength, his muscles are more developed and powerful. His voice losing the feminine pitch which characterises boyhood, becomes almost suddenly much more grave, and his beard is rapidly developed.

The corresponding changes in the female organism are manifested somewhat earlier, and show themselves by external forms familiar to every eye. The chest becomes enlarged, the shoulders expanded, and the pelvis acquires greater width, and the forms of womanhood become conspicuously visible. In temperate climates these changes are manifested at from 14 to 16 years of age. In warm climates they take place at from 10 to 11, and in colder countries are postponed to 17 or 18.

EFFECTS OF GROWTH.

51. Growth produces in the species a somewhat remarkable change in the mechanical qualities of the bones. This important part of our organism consists of three constituents, fibre, cartilage, and the earthy matter already mentioned called *phosphate of lime*. From the fibre they derive their toughness; from the cartilage their elasticity, and from the lime their hardness and firmness. Nothing can be more admirable in the economy of our body than the manner in which the proportion of these constituents adapts itself to the habitudes of age. The helpless infant, exposed by a thousand incidents to external shocks, has bones, the chief constituents of which being gristly and cartilaginous, are yielding and elastic, and incur little danger of fracture. Those of the youth, whose augmented weight and increased activity demand greater strength, have a larger proportion of the calcareous and fibrous elements, but still enough of the cartilaginous to confer upon the solid framework of his body the greatest firmness, toughness, and elasticity. As age advances, prudence and tranquil habits increasing, as well as the weight which the bones have to sustain, the proportion of the calcareous constituent increases, giving the requisite hardness and strength, but diminishing the toughness and elasticity.

While the bones thus change their mechanical qualities as age advances, they diminish in number, the frame consequently having fewer joints and less flexibility. The bones of a child, whose habits require greater bodily pliability, are more numerous than those of an adult, several of the articulations becoming ossified between infancy and maturity. In like manner, the bones at maturity are more numerous than in advanced age, the same progressive ossification of the joints being continued.

It has been ascertained by anatomists that, on attaining the adult state, the number of bones constituting the framework of the human body is 198; of which 52 belong to the trunk, 22 to the head, 64 to the arms, and 60 to the legs.

52. This wonderful solid structure is moved by a mechanical apparatus, consisting of about 400 muscles, each of which is attached at its extremities to two points of the body, more or less distant from each other, which it has the power of drawing towards each other by a contractile property peculiar to it. These muscles, however, being passive pieces of mechanism, are moved as already mentioned by the nerves, while the nerves themselves are moved by the will, and here the material mechanism ends, and the intellectual or the spiritual begins.

As age advances, the organs lose their suppleness and elasticity; the weight of the body undergoes a sensible diminution; the powers of digestion and assimilation are gradually impaired; the vital flame decreases in splendour, and flickering in its socket, at length, and with apparent reluctance, goes out.

53. Death, however, by the mere effect of age, is extremely rare, being in most cases produced by accidental causes, to which imprudence exposes us. Innumerable examples prove to how great an extent life may be prolonged beyond its average limits. Without citing the extraordinary examples of longevity found in the records of the first ages of the world, supplied by the Sacred Scriptures, examples sufficiently numerous may be produced nearly from our own times.

One of the most remarkable examples of longevity which modern times have presented, is that of a poor fisherman, an inhabitant of Yorkshire, by name Henry Jenkins, who died in 1670, at the age of 157. Peculiar circumstances have incidentally supplied evidence of the great ages of this individual, and two of his sons. He was summoned on a certain occasion before a court of justice, to give evidence of a fact which had occurred 140 years previously; and he appeared before the tribunal attended by his two sons, the younger of whom had attained the age of 100, and the elder that of 102. Various other examples are cited of nearly equal longevity, but for the most part they refer to times or places at which the registers of births and deaths were not kept with such regularity as to entitle the statement to confidence. It is, however, extremely rare to find an individual who has exceeded the age of 100. According to the bills of mortality of the City of London, it appears that, of 47000 deaths which took place in the ten years ending in 1762, there were only 15 centenarians. In France, during the three years ending with 1840, there were 2,434993 deaths, of which 439 were reputed centenarians, which would give a proportion of about 1 in 5500.

54. One of the saddest spectacles presented by the analysis of the general progress and termination of human life, is the vast proportion of our race which are swept away in the first years of their existence; a circumstance which can only be explained by the care which infancy requires, and the inability of the poor and labouring classes to bestow it. It appears, from the statistical records so accurately kept in France, that of every 100 children born, 24 die in the first year; 33 in the first two years; 40 in the first four years; and 50 in the first twenty years. Thus it appears that only half the children born in France survive for the purpose of the continuance of the race. According to similar records published in England, it appears that 40 in 100 die in the first 5 years, and 11 more between that and 20; so that the survivors at 20 are something less than half the number born.

Fig. 22.—ETHIOPIAN.

COMMON THINGS.

MAN.

CHAPTER III.

55. Average duration of life.—56. In England and France.—57. Great mortality of foundlings.—58. Average number of children per marriage.—59. Influences which produce permanent changes in man.—60. Indications of a common origin for the human race.—61. Naturalists in this verify the Hebrew Scriptures.—62. The five races of men.—63. The Caucasian variety.—64. The Mongol.—65. The Malay.—66. The Ethiopian.—67. The American.—68. The relation of languages.—69. The limits of physiological and psychological speculation.—70. Man material and intellectual.—71. Connection between the physical and the intellectual.—72. Personal identity.—73. Analysis of the constituents of the human body.—74. The absurd consequences of materialism.—75. Further difficulties from the question of personal identity.—76. The body said to change altogether once a month.—77. The intellectual part however suffers no change—materialism disproved.—78. Regularity of moral and intellectual phenomena.—79. Difference between them and physical phenomena.—80. Freedom of will does not prevent these phenomena, considered collectively, from observing general laws.—81. Example of statistical phenomena.—82. Frequency of marriages.—83. Constant proportion of unequal marriages.—84. Proportion of illegitimate children.—85. Prevalence of crime, and proportion of acquittals.—86. Acts of forgetfulness—number of unaddressed letters posted.—87. General conclusion.

55. THE mean duration of life in England and Wales during the 40 years ending with the year 1840, varied from thirty-one to thirty-seven years, the variation, however, not being regular, and its mean value being thirty-four years.

56. A similar calculation applied to the population returns in France during the 36 years ending with 1852, showed a progressive increase of the mean duration of life. During the first eight years, ending with 1824, the mean length of life was 31·8 years, and during the last eight years, ending with 1852, it was 36·7. Its mean value for the whole interval of 36 years being 34·2 years, the same as in England.

Now, it will not fail to strike every one that this term of life is greatly below that which would result from general observation, independently of all statistical results. A person dying at thirty-four would be lamented by all as one taken away prematurely in the prime of life. This discrepancy between the results of statistics and common observation admits of easy explanation. The estimate made by common observation is tacitly based upon a rough average taken of the ages at which those die who have already entered upon the scene of life, and have been recognised by all as members of the human family. The more exact calculations of statistics include rigorously all that are born into the world, of whom so large a proportion die in their first year; and as we have seen, not less than 4-10ths in that term of infancy, during which they can scarcely be said to be recognised by common observation as forming part of the population. To render the results of the computation of the absolute duration of life applicable to the 6-10ths which arrive at the adult state, it will only be necessary to augment the computed duration of life in the ratio of 6 to 10. If, therefore, as has been shown, the actual mean duration of life in England and France be 34 years, the mean length of life of those who survive their infancy will be 56 years, which, it is evident, is in complete accordance with common observation.

57. How much the preservation of life during infancy is dependent on parental care, is rendered conspicuously apparent by the melancholy fact established by the statistical returns, that 80 per cent., or four in every five of the children abandoned in France as foundlings, die in their first year.

58. The number of children resulting from each marriage is found by the simple method of comparing the total number of annual legitimate births with the total number of annual marriages. By this process, it appears that the mean number of children to every two marriages in France is seven, and in England eight, these mean results being subject to a very slight variation from year to year.

59. The human race, as is well known, consists of a considerable number of varieties, differing one from another in personal appearance, character, language, in their average degree of

moral and intellectual powers, and in their geographical distribution. Those whose observations have been mainly confined to the extremes of form and colour, and who have not reflected on the wonderful changes to which all organised beings are subject by various external physical causes,—changes which, when once superinduced, are transmitted, not only in man, but in inferior animals, and even in plants, through the series resulting from reproduction,—have viewed the differences observed among the members of the human family, not as characteristics of so many varieties of a single species, but as marks distinguishing different species of the same genus. We have, however, the authority of the greatest living observer of nature, as developed in the animal kingdom, in opposition to this cheerless doctrine.

60. "The permanence of certain types, in the midst of most opposite influences," says Humboldt, "especially of climate, appeared to favour this view, notwithstanding the shortness of the time to which the historical evidence applied; but in my opinion, more powerful reasons lend their weight to the other side of the question, and corroborate the unity of the human race. I refer to the many intermediate gradations of the tint of the skin, and the form of the skull, which have been made known to us, by the rapid progress of geographical science in modern times, to the analogies derived from the history of varieties in animals, both domesticated and wild, and to the positive observations collected respecting the limits of fecundity in hybrids. The greater part of the supposed contrasts, to which so much weight was formerly assigned, have disappeared before the laborious investigations of Tiedemann on the brain of negroes and of Europeans, and the anatomical researches of Vrolik and Weber, on the form of the pelvis. When we take a general view of the dark-coloured African nations, on which the work of Prichard has thrown so much light, and when we compare them with the natives of the Australasian Islands, and with the Papuas and Alfourous, we see that a black tint of skin, woolly hair, and negro features, are by no means invariably associated. So long as the western nations were acquainted with only a small part of the earth's surface, partial views almost necessarily prevailed. Tropical heat, and a black colour of the skin, appeared inseparable. 'The Ethiopians,' said the ancient tragic poet, Theodectes of Phaselis, 'by the near approach of the Sun-God in his course, have their bodies coloured with a dark sooty lustre, and their hair curled and crisped by his parching rays.' The campaigns of Alexander, in which so many subjects connected with physical geography were originally brought into notice, occasioned the first

discussion on the problematical influence of climate on nations and races." *

61. Thus it appears that according to the principles admitted by the most eminent physiologists and naturalists, whether assenting or not to the doctrines of Christianity, there is nothing in the natural differences observable between different parts of the human race distributed over the globe, which is incompatible with that part of the narrative of the origin of mankind, consigned to the Hebrew Scriptures, which traces the whole human race to a single pair and constitutes them therefore as members of a common family.

62. Naturalists and physical geographers have distributed by various classifications these varieties of men, and have generally given them the somewhat vague and improper name of races. Thus Blumenbach classifies them into five races, called the Caucasian, the Mongolian, the American, the Ethiopian, and the Malay. Some authorities reduce this number to four, regarding the Malay merely as a variety of the Ethiopian.

Dr. Prichard, on the other hand, classifies the human family into seven races, which he calls:—

The Iraunian,
The Turanian,
The American,
The Hottentots and Bushmen,
The Negroes,
The Papuas,
And the Alfourous.

This division is objected to by Humboldt, and does not appear to have obtained general acceptation.

63. The Caucasian race (fig. 20), p. 49, in which the population of Europe is included, is distinguished by the beauty of the oval form of the head and countenance; by the large facial angle, amounting to about 90°; by the consequent upright forehead; the horizontal direction of the eyes; the absence of all projection of the cheeks; fine smooth hair; and the fair tint of the skin. They are, however, still more remarkable for the high degree of perfection to which their moral and intellectual faculties speedily attain; a quality which has rendered them the most civilised people of the globe. They occupy all Europe, western Asia as far as the Ganges, and the northern part of Africa. They have derived their name of Caucasian from the supposition that they came originally from the country north of Mount Caucasus, lying between the Caspian and the Black Sea. Although generally fair, they include various

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* Cosmos, vol. i. p. 352, translation.

shades, from the extreme fairness of the red-haired northern to the swarthy inhabitants of certain parts of the Spanish peninsula and of North Africa.

64. The Mongol variety (fig. 21) p. 65, differs in several respects from the Caucasian. Their face is flat; their forehead low, oblique, and angular; their cheek-bones salient; their eyes small, and set obliquely; the chin slightly prominent; the beard sparse; the hair long, straight, and black; and the complexion a yellow or sallow olive.

The languages spoken by the Mongol variety are extremely different from those of the Caucasian, being for the most part monosyllabic. This variety is spread eastwards over the countries occupied chiefly by the Caucasian races. They are encountered in the great desert of Central Asia, where the Kalmucks and other Mongol tribes are still nomadic. Almost the whole population of the eastern part of Siberia is Mongol; but the nation which forms the most remarkable part of this race is the Chinese, whose vast empire was, of all parts of the world, the first civilised; although the exclusive spirit of their laws and customs, which has raised a barrier between them and the rest of mankind, has kept them stationary for ages.

65. The Malay variety occupies the islands of the Indian Archipelago, New Zealand, Chatham Islands, the Society Group, the Philippines and Formosa, and several of the Polynesian Islands. They are dark; have lank, coarse, and black hair; flat faces; and eyes obliquely set. In their moral and social qualities, they vary extremely in different localities; some being active and ingenious, mild and gentle, and considerably advanced in the arts of life; while others are ferocious, vindictive, daring, and predatory. To this variety are generally referred a considerable part of the population of the extreme north of Europe, such as the Greenlanders, Laplanders, Samoides, and Esquimaux.

66. The Ethiopian variety, or Negro (fig. 22), is characterised by his compressed skull, small facial angle, flat nose, salient jaws, thick lips, woolly and crisped hair, and black skin. The habitation of this variety is south of Mount Atlas, and is spread over all the remainder of the African continent, Madagascar, Australia, Mindanao, Gillolo, the islands of Borneo, Sumbawa, Timor, and New Ireland. It consists of several sub-varieties, such, for example, as the Mozembics, the Bushmen, and the Hottentots.

67. The American variety is generally characterised by a copper-coloured skin, sparse beard, and long black hair. They differ extremely, however, one from another; some tribes manifesting a close analogy to the Mongols, others approaching close to the external characters of Europeans; the nose is generally

prominent, like the European; the eyes being large, regular, and disclosed by widely opened lids.

68. The question of the descent of all these varieties from a common origin, is closely connected with the analysis of languages. Nothing affords a more convincing proof of identity of origin than the discovery of similar forms of expression and terms, having like roots in the tongues spoken by distant people. "But here," observes Humboldt, "as in all fields of ideal speculation, there are many illusions to be guarded against, as well as a rich prize to be attained. Positive ethnographical studies, supported by profound historical knowledge, teach us that a great degree of caution is required in these investigations concerning nations, and the language spoken by them at particular epochs. Subjection to a foreign yoke, long association, the influence of a foreign religion, a mixture of races, even when comprising only a small number of the more powerful and more civilised emigrating race, have produced in both continents similar recurring phenomena, viz., in one and the same race two or more entirely different families of languages, and in nations differing widely in origin, idioms belonging to the same linguistic stock. Great Asiatic conquerors have been most powerfully instrumental in the production of striking phenomena of this nature.

"But language is an integral part of the natural history of the human mind; and, notwithstanding the freedom with which the mind pursues perseveringly, in happy independence, its self-chosen direction under the most different physical conditions,—notwithstanding the strong tendency of this freedom to withdraw the spiritual and intellectual part of man's being from the power of terrestrial influences, yet is the disenthralment never completely achieved. There ever remains a trace of the impression which the natural disposition has received from climate, from the clear azure of the heavens, or from the less serene aspect of a vapour-loaded atmosphere. Such influences have their place among those thousand subtle and evanescent links in the electric chain of thought, from whence, as from the perfume of a tender flower, language derives its richness and its grace."

By maintaining the unity of the human species, we at the same time repel the cheerless assumption of superior and inferior races of men. There are families of nations more readily susceptible of culture, more highly civilised, more ennobled by mental cultivation than others, but not in themselves more noble. All are alike designed for freedom; for that freedom which in ruder conditions of society belongs to individuals only, but where states are formed, and political institutions enjoyed, belongs of right to the whole community. "If," says Wilhelm von Humboldt, "we would point to an idea which all history throughout its course discloses as ever establishing more firmly and extending more widely its salutary empire,—if there is one idea which contributes more than any other to the often-contested, but still more often misunderstood, perfectibility of the whole human species,—it is the idea of our common humanity tending to remove the hostile barriers which prejudices and partial views of every kind have raised between men; and to cause all mankind, without distinction of religion, nation, or colour, to be regarded as one great fraternity aspiring towards one common end, the free development of their moral faculties. This is the ultimate and highest object of society; it is also the direction implanted in man's nature, leading towards the indefinite expansion of his inner being. He regards the earth and the starry heavens as inwardly his own, given to him for the exercise of his intellectual and physical activity. The child longs to pass the hills or the waters which surround his native dwelling, and his wish indulged, as the bent tree springs back to its first form of growth, he longs to return to the home which he had left; for by a double aspiration after the unknown future and the unforgotten past, after that which he desires and that which he has lost, man is preserved by a beautiful and touching instinct from exclusive attachment to that which is present. Deeply rooted in man's most innate nature, as well as commanded by his highest tendencies, the full recognition of the bond of humanity, of the community of the whole human race with the sentiments and sympathies which spring therefrom, becomes a leading principle in the history of man." *

69. When we come to trace the conduct of man as an individual member of the social body and to connect it with his physical organisation, we tread upon the interesting ground which forms the confines between the legitimate territories of the physiologist and psychologist, between the provinces of the natural philosopher and the theologian; and however closely our vocation and habitudes have attached us to the contemplation and investigation of mere physical laws, we cannot forbear to throw a passing glance into the spiritual world.

70. Man's nature, according to the admission of all, is a compound of the material and the intellectual. According to some, to whom, on that account, the name of *materialists* has been given, the intellectual is a mere function or property of the material part of our nature. According to others, the intellectual is a function of a spiritual essence, which is independent of our material organi-

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* Cosmos, translation, p. 354.

sation, though inseparably connected with it during human life. The name of *spiritualists* has, accordingly, been given by contradistinction to the latter.

71. Our nature being thus compound, let us see how far we can trace the connection between its mere physical part and the thinking and intelligent principle which abides in it.

72. There is a principle called in metaphysics personal identity, which consists in the internal consciousness by which each individual knows his past existence, so as to be able, with the greatest certainty of which the judgment of our minds is susceptible, to identify himself existing at any given moment with himself, existing at any former time and place. Nothing in human judgment can exceed the clear certitude which attends this consciousness. The Duke of Wellington, on the eve of his death at Walmer, had an assured certainty that he was himself the same individual intelligent thinking being, who, on the 18th of June, 1815, commanded at Waterloo the allied armies. Now to what, let us ask, did this intense conviction and consciousness of identity apply? What was there in common between the individuals who died at Walmer and who commanded at Waterloo? The reply to this question will require that we shall recur for a moment to our physical organisation.

73. The human body consists of bones, flesh and blood, each of which is, however, itself a compound substance, and the whole is impregnated in a large proportion with water. Thus, the quantity of blood in an average body is 20 lbs., of which 15 lbs. are water, the other 5 lbs. consisting of those material constituents which are necessary for the supply of the growth or the repair of the body. The flesh, commonly so called, is pervaded by blood-vessels, and therefore, strictly speaking, is a combination of flesh and blood. In like manner, the bones are pervaded to their very centres by innumerable blood-vessels, so minute as to be microscopic, by which their growth is supplied and their waste repaired. Taking, however, the terms flesh, blood, and bone in their proper meaning, excluding from each the water with which it is impregnated, and excluding from the flesh and bone the blood which pervades them respectively, the material constituents of an average human body may be thus stated:—

Bone	14 lbs.
Flesh and blood	24
Water	116

The bone, when submitted to analysis, is shown to consist of certain earthy matter, the chief part of which is lime and a substance called *gelatine;* this gelatine itself being a compound, one half of which is pure charcoal, called by chemists *carbon*, and the other a combination of the gases which constitute common air and water. From this analysis it follows that, in round numbers, the 14 lbs. of bone which enter into the composition of the human body, omitting minute fractions and insignificant quantities, consist of 10 lbs. of lime, 2 lbs. of charcoal, combined with 2 lbs. weight of the gases just mentioned.

A similar analysis of flesh and blood shows that they consist, in nearly equal parts, of charcoal and the same gases, so that the 24 lbs. weight of these substances which enter into the composition of an average body, are resolved into 12 lbs. of charcoal, combined with an equal weight of the gases already mentioned.

Thus, in fine, the ultimate materials of the average human body, are 14 lbs. of charcoal and 10 lbs. of lime, impregnated with 116 lbs. of water, and 14 lbs. weight of the gases which form air and water, that is, *oxygen*, *nitrogen*, and *hydrogen*.

74. Now those who think that the intellectual principle residing in the human body is nothing more than a quality or a property arising from the matter composing it, must be able to imagine how 14 lbs. of charcoal, 10 lbs. of lime, and 116 lbs. of water can be so mixed up with 14 lbs. of air as to make a material thing—machine let us call it—which can feel, think, judge, remember, and reason. Let us try to imagine, for example, the possibility of such a mass of charcoal, lime, and water discovering the existence, position, and motion of the planet Neptune before it was ever seen; of ascertaining the periodicity of the planetary inequalities, countless ages before many of these inequalities had passed through one of their periods; of inventing the printing press, the ship, the steam-engine, and the electric telegraph; of composing "Paradise Lost;" of producing the Transfiguration and the Antinous, or of designing the Parthenon!

But it will be answered, that the power of intelligence is ascribed not to the mere inert materials of the human body, but to their organisation. What, then, is organisation? Let us not be misled by a long and learned word. Organisation is, and can be, but some particular way of arranging the parts of which any thing is composed. Thus, a given number and weight of stones may be arranged in a thousand different ways, so as to compose as many different structures, but each such structure is still a mere mass of stone. It is true that the simple material elements which we have enumerated above may be, and are, curiously combined and arranged, so as to produce the human body. But after this is accomplished, we are left as far as ever from any explanation as to how the mere arrangement and peculiar juxta-position of the material atoms, thus composing such a body, can produce the prodigious powers of intellect which have been developed in the history of the progress of the human mind.

75. But even admitting a supposition apparently so impossible, the question of personal identity, which we have referred to above, will raise an insuperable objection to it. Physiologists and anatomists have proved that the matter which composes our bodies is subject to continual change. Every part of our organisation, even to the innermost cores of our bones, is subject to this never-ceasing process of mutation. The food which we take into our stomachs contains, combined with some other matters, all the constituents necessary to compose our bodies. In the process of digestion, those parts which are unsuited to our bodies are rejected, and the several suitable parts passing into the blood, are carried by it through the circulating apparatus to all parts of the system; to the bones, as well as to the flesh and softer parts; the peculiar constituents necessary for the maintenance of each part respectively being deposited there in the proper proportion, and the waste carried away. This process of constant renovation and removal of used-up matter—of offal, as it were—goes on equally throughout the bones as throughout the softer parts. Now, it will be evident that, in such an unceasing process of rejection and renovation, the entire mass of matter composing the body must in a certain period, longer or shorter, undergo a complete change, so that, corporeally speaking, an individual, at any given period of his life, has not in his entire composition a single material atom which he had at a certain previous period. It was the opinion of former anatomists and physiologists, that the body undergoes this complete change of the matter composing it every seven years; but more recent and exact observations and calculations, founded upon rigorous analysis of the phenomena of digestion, circulation, respiration, and other less important functions, have proved this estimate to err by excess.

The 116 lbs. weight of water which forms three-fourths of the matter composing our bodies, is rejected with great rapidity in respiration, transpiration, and natural discharge. The carbon is expired with each action of the lungs in large quantities, combined with oxygen, another constituent of our bodies, in the form of carbonic acid. The lime escaping in other ways is rejected from our bones, and replaced by a fresh supply. There is not a movement of the body, whether voluntary or involuntary; not an action of a member, a muscle, or a nerve; not a pulsation of the heart or of an artery; not a peristaltic motion of the intestines, which is not the proximate cause of the rejection of used-up matter and the demand for a fresh supply from the digestive apparatus, just as in a machine the wear and tear of the parts is proportional to the force and continuance of their motions.

76. Although the rapidity with which the materials of the body are thus changed varies in comparing one individual with another, according to their varying habitudes and occupations, it appears that a total change of the material constituents of the body takes place within an interval much shorter than was supposed by the early physiologists. According to some authorities, the average length of this interval does not exceed thirty days. It is, however, generally agreed that it is a very brief period.*

77. This then being the case, let us again ask what is it that was identical in the Duke of Wellington dying at Walmer in Sept. 1852, with the Duke of Wellington commanding at Waterloo in June, 1815? Assuredly it was not possible that there should have been a single particle of matter common to his body on the two occasions. The interval consisting of thirty-seven years and two months, the entire mass of matter composing his body must have undergone a complete change several hundred times—yet no one doubts that there was *something* there which *did not* undergo a change except in its relation to the mutable body, and which possessed the same thought, memory, and consciousness, and constituted the personal identity of the individual; and since it is as demonstrable as any proposition in geometry that *that something* which thus abode in the body, retaining the consciousness of the past, could not have been an atom, or any number of atoms, of matter, it must necessarily have been something *not matter*, that is to say, something *spiritual.*

Habituated for so long a period to the rigorous logic of physics and mathematics, I confess I can see nothing in its results more conclusive than this proof of the existence of a spiritual essence connected with the human organisation. At this point, however, the support which the physical inquirer can offer to the theologian terminates. If there is nothing in the disorganisation of the human body and the phenomena of death to demonstrate the simultaneous destruction of the spiritual principle, the existence of which is thus established, there is, on the other hand, nothing to prove its continued existence, and for that we are thrown upon the resources of revelation, and this might indeed have been foreseen; for if the continued existence of the spirit, or, in other words, a future state, were capable of demonstration by the

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* We are not aware of any dissentient from the complete periodical change of matter composing the body, except Professor Milne Edwards, who, without absolutely denying the principle, thinks that it has not been satisfactorily demonstrated.

ordinary faculties of the mind, it would have been incompatible with the divine economy to have rendered it the subject of revelation. God does not suspend the laws of nature to reveal by miraculous means those truths which are discoverable by the exercise of our natural faculties.

78. As the motions and changes produced upon inert matter are physical and mechanical, so human actions are moral and intellectual phenomena. By duly comparing together the former, we are enabled to arrive at generalisations which are the expression of laws, the knowledge of which enables us to foresee, with certainty and precision, how any proposed bodies will comport themselves at any future time, and in any given place, under given conditions. It might, therefore, be naturally expected that the moral and intellectual phenomena of human actions, coming as truly within the range of natural facts as mere physical phenomena, could be equally classified and generalised, and that, consequently, natural laws might be equally established, by the knowledge of which this latter class of phenomena could, under given conditions, be predicted as clearly and certainly as the former.

79. An essential difference, however, between the two classes of phenomena renders a corresponding distinction in the expression of the general laws to which they are subject, necessary. Bodies consisting of mere inert masses of matter are susceptible of no motion save what they derive from the operation of external forces; and when such forces are given, their effects can be calculated and predicted. But the moral and intellectual phenomena here referred to, proceed from an internal and spontaneous act of the will of the individual, which cannot be known antecedently by the individual himself, and still less by others. The will also being absolutely free, the individual may, under given conditions, act in any conceivable manner; and consequently, as regards such an individual, the actions cannot be reduced like physical facts to a general law. Men being thus free agents, and their actions being subject to impulses arising from characters, temperaments, passions, surrounding excitements and personal circumstances infinitely various, it might naturally be expected that the record of the actions of any large society of individuals, such as the population of a city, province, or country, would present a confused and heterogeneous mass of facts altogether unsusceptible of rule, law, or generalisation; and that, consequently, such record preserved of the past would throw no light whatever upon the probable future of the conduct of such a multitude of free agents.

80. Careful and accurate analyses of the acts of men, so far as

they have been registered in public records entitled to confidence, prove, however, that such is not the case; and that although they individually act with perfect freedom of will, yet their acts collectively conform to laws scarcely less rigorous than that of gravitation, and that, consequently, although the freedom of individual will renders it impossible that the individual acts can be predicted, the same impossibility is not at all applicable to collective acts. On the contrary, statistical records prove incontestably that acts which, taken individually, cannot for a moment be doubted to proceed from the impulses of a free and independent will, taken collectively, recur with as much regularity and precision as the fall of a heavy body by gravitation. It is true that such acts, when classified and generalised, give average results from which the individual cases depart more or less on the one side than on the other; but this is no more than takes place with the physical phenomena of inert matter, all of which oscillate round a mean state, the departures from which have received the name of *perturbations.* In moral and intellectual, as well as in physical and mechanical phenomena, there are also perturbations, but, like the latter, these are also confined within narrow limits. The sole difference in the two classes of natural effects being, that in the one case the condition of bodies may be predicted individually, while in the other it can only be predicted collectively.

81. Those who have prosecuted their researches most extensively in the modern science of Statistics, have proved that the effects of the free will of individuals composing large societies completely neutralise each other, and that such communities taken collectively act as if the whole body had by common consent agreed to follow a certain prescribed course of conduct, not only in matters which might be imagined to be more or less of common interest, but even in those in which no feeling could be imagined to be engaged, save the will, taste, personal inclination, or even caprice, of the individual.

82. There is, perhaps, no act of our lives which so exclusively concerns and interests us personally as that of marriage. Although parents and friends must be admitted to exercise more or less influence, yet, in the main, individuals of the different sexes are united together by their personal choice and inclination. This being the case, it might be imagined that the frequency of marriages, and the relative ages of the parties contracting them, would be as various as the tastes, feelings, inclinations, and personal characters of the individuals composing the community. Yet we find that such is not the case; but that, on the contrary, not only the frequency of marriages, but the relative ages of the parties contracting them, are subject to laws quite as rigorous as

those which govern the motions of the solar system. Thus we find, that in the same country, in a series of successive years, the same average number of marriages are contracted, the departures from the average being, like the planetary inequalities, small and self-compensatory. If there is a small excess in one year above the average, there is sure to be a corresponding deficiency in another.

Thus, for example, in England and Wales during the five years from 1845 to 1849 inclusive, the average number of marriages was 142800, and the actual number in each year varied from this average by not more than a few hundreds. In 1851 and 1852, with an increased population, the average number was increased to 156000, from which the variations were equally inconsiderable. In countries, however, where statistical registers are kept with more circumstantial precision than in England, results affording more striking illustrations of these principles may be obtained. In Belgium, for example, to the statistics of which the labours and talents of M. Quetelet have been directed, some very remarkable circumstances bearing on this question have been developed. Thus, it appears that, for a series of years before and after 1840, the average number of marriages contracted in that country was 29130. How completely obedient the population was in the fulfilment of this statistical law, may be seen by the following exact number of marriages contracted in the five years succeeding 1840:—

YEARS.	MARRIAGES.
1841	29876
1842	29023
1843	28220
1844	29326
1845	29210

Thus it appears that in 1841, 1844, and 1845, the number of marriages exceeded, while in 1842 and 1843 they fell just as far short of the average; just as the velocity of a planet near its perihelion exceeds, and near its aphelion falls short, of its mean motion.

83. But this is neither the only, nor by any means the most remarkable, example of the play of general laws in human actions, which, of all others, must be admitted to be the most completely voluntary. Thus, for example, when a man of 30 chooses a wife above 60, he can scarcely be imagined to be controlled by the influence of parents. Yet it appears that the frequency of such marriages is as regular as the annual motion of the sun. Take the following examples. In Belgium, the average number of men not above 30 marrying women above 60 annually is 6, and the

departures from this either way is usually limited to 5 or 7. If in one year there are 7 such marriages, it is sure to be preceded or followed immediately or mediately by another year in which the number is only 5. Again, the number of men between 30 and 45 contracting marriage with women above 60 is annually 18, subject to a small occasional variation one way or the other. In the same way, it appears that the number of men from 45 to 60 marrying women above 60 is annually 27.

The same regularity is found to characterise the number of marriages between couples within any other prescribed limits of comparative age.

84. The number of children resulting from each marriage cannot be considered as depending on will. But assuredly the calling into the world of illegitimate children must be admitted to have the character of a voluntary act; yet it is found, that in each country, the annual number of illegitimate children bears a fixed ratio to the number of marriage-born. In France and Belgium this ratio is 1 to 13. In England the proportion is found to be exactly the same. and this appears to occur, from year to year, in both countries with all the regularity of physical law.

85. The statistics of crime being especially susceptible of exact record, have been submitted to the same careful examination by M. Quetelet, from whose researches it appears, that in the same country the same number of crimes of the same description are committed annually; and this curious result is found equally to attend those classes of crimes which it would seem most impossible to foresee. But, connected with these criminal statistics, there is a circumstance still more curious and remarkable. It necessarily happens, in the administration of criminal justice, that, through the want of sagacity in the examining magistrates, and a multitude of fortuitous circumstances surrounding the accused, a considerable number of guiltless persons are brought to trial. Now, will it be believed, that such is the prevalence of general laws, that even in this class of moral phenomena, founded on the results of fallible judgment, a rigorous law prevails, and we find that, in each country, the proportion of persons charged with offences who are acquitted, is from year to year the same? Thus, for instance, in France, 39 in every 100 of those accused are as regularly acquitted as if the decisions of the juries were made by putting 61 black balls and 39 white ones into a box, and deciding the fate of the criminals by ballot.

86. It is not only, however, voluntary acts which are subject to this numerical regularity. Collectively speaking, persons remember and forget certain things with as much regularity as if memory and attention were the result of wheel-work. A very

common instance of forgetfulness is presented by persons posting letters without any address written upon them. The number of times this act of obliviousness annually happens is known with the greatest precision, inasmuch as such letters are transferred to and recorded in a bureau specially devoted to the purpose in each post-office. Now, it is found by the Post-Office returns in England and France, that the number of these unaddressed letters in each country is almost exactly the same from year to year. In London the number of such letters is about 2000, being at the rate of above 6 per day.

But connected with this is another circumstance equally remarkable. A certain proportion of these letters is found to contain money and other valuable enclosures; and, like the whole number, this proportion is also invariable.

87. The conclusion at which we arrive then is, that the great principle in virtue of which the Author of nature carries out His purposes by the operation of general laws is not, as it would first appear, incompatible with the freedom of human agency, and therefore with man's moral responsibility. The same character of generality attaches to the laws which govern the moral and intellectual phenomena of human actions, considered collectively, as those which attach to mere physical phenomena. But these laws not being applicable to human actions, considered individually, leave free will and moral responsibility inviolate.

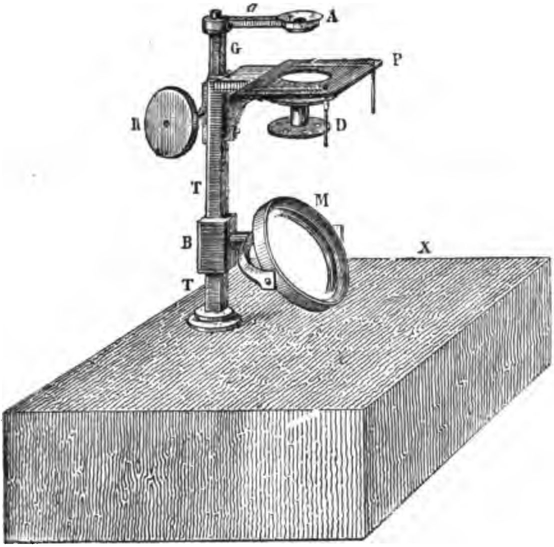


Fig. 15.—Simple Microscope.

MAGNIFYING GLASSES.

1. Magnifiers intermediate between spectacle-glasses and microscopes.—2. Variously mounted.—3. Extensive use in the arts.—4. Their magnifying power explained.—5. Visual magnitude.—6. Standard of visual magnitude.—7. Distance of most distinct vision.—8. Visual magnitude at ten-inch distance.—9. Magnifying power of a convex lens.—10. Effect of the same lens with different eyes.—11. Superficial and cubical magnifying power.—12. The eye to be placed close to the lens.—13. Magnifying power depends on focal length.—14. Focal length depends on convexity and materials of lens.—15. Lenses of different materials.—16. Spherical aberration less with a greater refracting material.—17. Diamond lens.—18. Magnitude of lens greater with more refracting material.—19. Advantages of gem lenses.—20. Superseded nevertheless by the improvement of compound microscopes.—21. Magnifiers for reading.—22. For miniature-painters and engravers.—23. For watch-makers, jewellers, &c.—24. Supports for these.—25. Pocket magnifiers.—26. Coddington lens.—27. Doublets.—28. Their optical effects.—29. Their advantages over single lenses.—30. Method of mounting them; triplets.—31. Mounting of hand-doublets.—32. Method of mounting doublets of high power for dissection and similar purposes.

1. Magnifying glasses hold an intermediate place between the spectacle glasses, used by weak-sighted persons, and the microscope; and when they possess considerable magnifying power, they

are sometimes called simple microscopes; but the term microscope is more generally applied to that class of optical instruments which consists of a combination of lenses, which are applicable to the examination of the most minute objects, and with amplifying powers much more extensive.

2. Magnifiers are very variously mounted according to the uses to which they are applied. The more simple forms, and those which have the least amplifying power, consist of a single lens, which is either convex on both sides, or plano-convex, or which may be concave on one side and convex on the other, provided the convexity be greater than the concavity. In fine, whatever be its form, it is essential that convexity shall prevail.

3. These glasses are of very extensive use in the arts. In all cases in which the objects operated upon are minute, the interposition of a magnifier is found advantageous, and often indispensable; thus, they are invariably used in different mountings by watch-makers, jewellers, miniature-painters, engravers, and others.

4. To render our explanation of these very convenient instruments intelligible, it will be necessary that the reader should be previously more or less familiar with what has been already explained in our Tracts on the Eye, on Optical Images, and on Spectacles; we shall, therefore, take for granted, that the contents of these Tracts are known to the reader.

We know no subject respecting which more inexact and erroneous notions prevail, than the amplification or magnifying effect produced by all optical combinations, from the simple convex lens to the most powerful microscope. The chief cause of all this confusion and obscurity may be traced to a neglect of the proper distinction between visual and real magnitude. The eye, as has been already explained, takes no direct cognizance of real magnitude, which it can only estimate by inference and comparison with the impressions of the sense of touch; these inferences and comparisons being often attended with complicated calculations and reasoning. If a proof of this be required, it may be found in the universally observable fact that objects which have the same visual magnitude often have real magnitudes enormously different; thus, for example, the apparent or visual magnitudes of the sun and moon are, as every one knows, equal; yet the real diameter of the sun is more than 400 times that of the moon.

5. It must be remembered that visual magnitude is determined by the divergence of lines drawn from the eye to the extreme limits of the object; it is measured, therefore, not like real magnitude by miles, feet, and inches, but by degrees, minutes, and seconds; thus, while the real diameter of the moon measures

about 2000, and that of the sun about 887000 miles, the visual diameter of the one and the other measures about half a degree.

The magnitudes of objects, as they appear with magnifying glasses, are all visual and not real. When an object seen by the interposition of such an instrument is said to be magnified so many times, it is therefore meant that it is so many times greater than it would be if the same object were seen with the naked eye; but since it has been shown in our Tract on the eye, that the visual magnitude of the same object seen with the naked eye varies, being greater as its distance from the eye is less, it follows, that the visual magnitude seen with the naked eye is an indefinite and variable standard, and in order that the visual magnitude of an object taken as the standard of magnifying power should be definite, it is necessary that the distance at which the object is supposed to be viewed by the naked eye should be stated. When, however, a person without any previous scientific instruction views an object with a magnifier, he becomes instantly conscious of its amplification; that is, that it appears larger than it would appear if he had viewed it without the interposition of the magnifier. The question is then, at what distance from his eye such a person would suppose the object to be looked at without the magnifier; and the reply which has been generally given to this question is, that he would suppose it to be viewed at that distance at which he would see it most distinctly.

6. This being admitted then, microscopists have generally agreed that the visual magnitude viewed with the naked eye, which should be taken as the standard of comparison in expressing the effect of magnifiers, is that which the object would have when viewed at the distance at which objects are most distinctly seen.

7. But here another difficulty arises. In the first place, the distance at which one individual can see an object most distinctly is not the same as that at which another will see it most distinctly; thus, while a far-sighted person will see most distinctly at the distance of 15 or 16 inches, and cannot see at all at the distance of 5 or 6 inches, a near-sighted person will see most distinctly at the latter distance, and only confusedly and indistinctly at the former. But even the same individual will see the same object most distinctly at one distance when it is strongly illuminated, and at a much less distance when it is feebly illuminated.

The distance of most distinct vision is therefore a variable and uncertain standard of comparison.

8. But there is one thing which is perfectly definite and certain. The visual magnitude of an object, at a given distance, is always the same, and quite independent of the powers and qualities of the eye which views it; it may, or may not, be distinctly

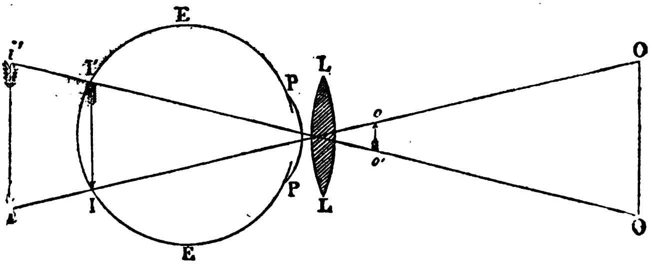
seen, or seen at all; but if seen, it can have but one visual magnitude. Thus an object, such as a coin, placed with its surface at right angles to the line of sight, at a distance from the eye equal to 10 times its own diameter, will have a visual diameter of $5\frac{3}{4}°$, and neither more nor less, no matter by what eye it is viewed. Seeing, then, that the distance of most distinct vision varies with different observers, and even with the same observer under different circumstances, and cannot therefore be taken as a standard of reference for visual magnitude, it has been generally agreed that magnifying powers shall be arithmetically expressed, by reference to visual magnitudes seen at 10 inches distance. Thus, if we say that such or such a magnifier magnifies an object three or four times, it is meant that it exhibits that object with a visual magnitude three or four times as great as that which the same object would have if viewed with the naked eye at 10 inches distance.

This distance of 10 inches has not been selected arbitrarily. It is considered to be about the distance at which average eyes would see an object most distinctly. It has the further convenience of lending itself with facility to calculation by reason of its decimal form. In other countries, the same distance very nearly has been adopted as a standard. Thus, French microscopists take 25 centimetres, which is a very small fraction less than 10 inches, as their standard.

9. This conventional standard being accepted, let us see in what manner an object is made to appear magnified by the interposition of a single convex lens.

Let E E fig. 1, represent a section of the eye, and *o o′* a small object placed at a much less distance from the eye than is compatible with distinct vision. According to what has been explained in former tracts, it will appear that the cause of indistinct vision is, in this case, that the image of *o o′*, produced by the humours of the eye, is formed not as it ought to be on the

Fig. 1.



retina at I I′, but behind it at *i i′*. According to what has been explained of optical images, the interposition of a lens, L L, of suitable convexity, will bring forward the image from *i i′* to I I′, and will therefore render the perception of the object distinct.

Now, it is most important to observe in this case, that the visual magnitude of the object, measured by the angle formed by the lines *o* I and *o′* I′, will be exactly the same as it would be if the eye could have seen the object *o o′* without the interposition of the lens: from which it appears that the lens does not, as is commonly supposed, directly augment the visual magnitude of the object, but only enables the eye to see the object with distinctness at a less distance than it could so see it without the interposition of the lens. We say *directly*, because, although the lens does not augment the visual angle of the object in the position in which it is actually viewed, yet, by enabling the eye to see it distinctly at a diminished distance, the visual angle of distinct vision, and therefore the apparent magnitude of the object, is increased in exactly the same proportion as the distance at which it is viewed is diminished.

To understand the magnifying effect of the lens, we must consider that the observer, seeing the object *o o′* with perfect distinctness, obtains exactly the same visual perception of it as if the object having the same visual magnitude were placed at that distance from the eye at which his vision would be most distinct. Let the lines passing through the extremities of the object therefore be prolonged to this distance of most distinct vision, and let an object, O O′, be supposed to be placed there, similar in all respects to the object *o o′*, and having the same visual magnitude. It will be evident, from what has been stated, that *o o′*, as seen with the lens, will have precisely the same appearance as the object O O′ would have if seen with the naked eye. The observer, therefore, considers, and rightly considers, that the magnifying power of the lens is expressed by the number of times that O O′ is greater than *o o′*; or, what is the same, by the number of times that the distance of O O′ from the lens, that is the distance of most distinct vision, is greater than the distance of the object from the lens.

It follows, therefore, generally, that the magnifying power of the lens will be found by dividing the distance of most distinct vision by the distance of the object from the lens.

10. Adopting this method of estimating the magnifying power, it would follow that the same lens would have different magnifying powers for different eyes, inasmuch as the distance of most distinct vision for short sight is less than that for average sight, and less for average sight than for far sight.

To make this more clear, let E, fig. 2, represent an average sighted eye; E′ (fig. 3) a short-sighted eye, and E″, fig. 4, a far-sighted eye. Let the same small object, L M, be placed at the same distance from each of them, and let the distance of most distinct vision for the first be E *l*; for the second E′ *l*′, and for the third E″ *l*″. If, by the interposition of a lens, the object L M be rendered distinctly visible to each of these three eyes, it will appear at *l m* to E, at *l*′ *m*′ to E′, and at *l*″ *m*″ to E″; its apparent magnitude, therefore, to the three eyes will be in the exact ratio of their respective distances of most distinct vision, and consequently the magnifying power to E′ will be less, and to E″ greater than to E.

Fig. 2.

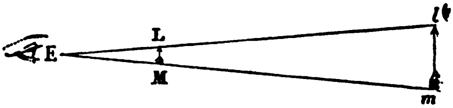


Fig. 3.

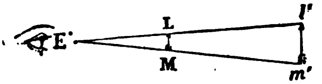
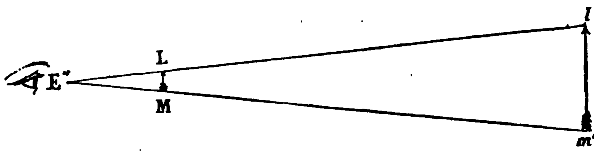


Fig. 4.



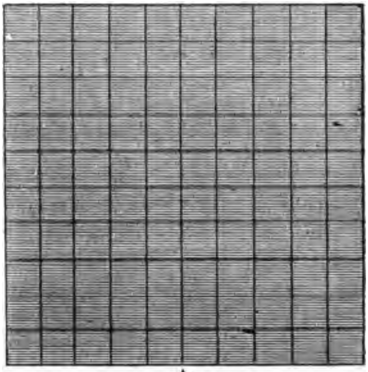
It must, however, be observed, that in this, which is the commonly received explanation, a circumstance of some importance is omitted, which will modify the conclusion deduced from it. To produce distinct vision with a given lens, L L, the distance of the object from the lens will not be the same for different eyes; for short sight the object must be nearer, and for long sight more distant than for average sight.

Now, if this variation of the distance from the lens, or of the focus, as it is called, for different eyes vary in the same proportion as the distance of most distinct vision (and it certainly does not differ much from that proportion), it will follow, contrary to the received doctrine, that the magnifying power of the same lens, will be the same for all eyes, whether they have average sight, long sight, or short sight.

11. It is contended by some that the magnifying power is more properly and adequately expressed by referring it to the superficial than to the linear dimensions of the objects.

Fig. 5.

Fig. 6.



To illustrate this, let us suppose the object magnified to be a square such as *a*, fig. 5. Now, if its linear dimensions, that is its sides, be magnified 10 times, the square will be increased to the size represented at A (fig. 6); its height and breadth being each increased 10 times, and its superficial magnitude being consequently increased 100 times, as is apparent by the diagram.

Now, it is contended, and not without some reason, that when an object, such as *a*, receives the increase of apparent size, represented at A, it is much more properly said to be magnified 100 than 10 times.

Nevertheless, it is not by the increase of superficial, but of linear dimensions that magnifying powers are usually expressed. No obscurity or confusion can arise from this, so long as it is well understood that the increase of linear, and not that of superficial dimension, is intended. Those who desire to ascertain the superficial amplification, need only take the square of the linear; thus, if the linear be 3, 4, or 5, the superficial will be 9, 16, or 25, and so on.

It might even be maintained, that when an object having length, width, and thickness, a small cube or prism of a crystal for example, is magnified, the amplification being produced equally on all the three dimensions, ought to be expressed by the cube of the linear increase; thus, for example, if the object, being a cube, be magnified 10 times in its linear dimensions, it will acquire 10 times greater length, 10 times greater breadth, and 10 times greater height, and will consequently appear as a cube of 1000 times greater volume.

In this case, however, as in that of the superficial increase, the calculation is easily made by those who desire it, when the linear increase is known.

12. In all cases in which magnifying lenses are used, except where the lens is large, and the magnifying power low, the eye of the observer should be placed as close as possible to the lens, the pupil being as nearly as possible concentric with the lens; for since the pencils of rays, which proceed from the extreme points of the object, intersect at an angle equal to that formed by lines drawn from the extremities of the object to the centre of the lens, they will diverge after passing through the lens, at the same angle; and the farther the eye is removed from the lens, the more rays it will lose, and beyond a certain limit of distance, a part only of the object will be visible.

13. Since eyes of average sight are adapted to the reception of parallel rays, an object seen through a lens by them will be distinctly visible, only on the condition that its distance from the lens shall be equal to the focal length; for, in that case, the rays which diverge from each point of the object, will emerge from the lens parallel, and therefore suitable to the power of the eye.

It is for this reason that the magnifying powers of lenses are estimated, by comparing their focal lengths with the distance of distinct vision. For since the focal length is always the distance of the object from the lens for average eyes, the distance of distinct vision, divided by it, will, according to what has been explained, be the magnifying power of the lens for such eyes.

14. The focal length of a lens will be less in proportion as its refracting power upon the light transmitted through it is greater; but the refracting power of the lens depends partly on its convexity and partly on its material.

With the same material the refracting power will be greater and the focal length less, as the convexity is increased; and, on the other hand, with a given convexity, the refracting power will be greater, and the focal length less, as the refracting power of the material, of which the lens is made, is greater. Thus, for example, if two lenses be composed of the same sort of glass, that which has the greater convexity will have the less focal length; and if, on the other hand, two lenses, one composed of glass and the other of diamond, have equal convexities, the latter will have a less focal length than the former; because diamond has a greater refracting power than glass.

15. It will be evident, from what has been explained, that if two lenses be formed of materials having different refracting powers, such for example as glass and diamond, so as to have equal focal length, that which has greater refracting power will have the less convexity.

If two lenses therefore be formed, having the same magnifying power, one of glass and the other of diamond, the latter will have less convexity than the former.

From what has been explained on the subject of spherical aberration, in our Tract upon Optical Images, it will be understood, that the more convex a lens is, the less its diameter must be, for if its diameter exceeds a certain limit relatively to its convexity, the spherical aberration will become so great as to render all vision with it confused and indistinct. This is the reason why all lenses of high magnifying power and short focal length are necessarily small.

16. But since the spherical aberration depends on, and increases with the convexity of the lens, other things being the same, it follows that if two lenses, composed of different materials, have equal focal lengths, that which has the less convexity will also have less spherical aberration.

17. Now, as according to what has been explained above, a diamond lens has less convexity than a glass lens of the same focal length, it will, if it had the same diameter, have less spherical aberration, or, what is the same, it will admit of being formed with a greater diameter, subject to the same aberration.

18. In lenses of high magnifying powers, and which are consequently of small dimensions, any increase of the diameter which can be made without being accompanied with an injurious increase of aberration, is attended with the advantage of transmitting more light from each point of the object to the eye, and therefore of rendering the object more distinctly visible. It was on this account that, when single lenses of high magnifying power were thought desirable, great efforts were made to form them of diamond, and other transparent gems having a refracting power greater than that of glass.

19. Sir David Brewster, who first suggested the advantage of this, succeeded in getting lenses of great magnifying power, made of ruby and garnet; he considered those made from the latter stone to surpass every other solid lens: the focal length of some of those made for him was less than the 1-30th of an inch, the magnifying power being more than 300.

20. All these and similar efforts made by Messrs. Pritchard and Varley, aided by the genius and science of the late Dr. Goring, have, however, happily for the progress of science, been subsequently rendered unnecessary by the invention of methods of producing good achromatic object-glasses of high power for compound microscopes, so that the range of usefulness of simple microscopes, or magnifying glasses, is now limited to uses and researches in which comparatively low magnifying powers are sufficient.

21. The most feeble class of magnifying glasses are those occa-

sionally used for reading small type, by persons of very weak sight; they consist of double convex lenses of 5 or 6 inches focal length, and having consequently a magnifying power no greater than two; they are usually double convex lenses, from 2 to 3 inches in diameter, mounted in tortoise-shell or horn, with convenient handles.

22. Magnifiers of somewhat shorter focal length and less diameter, similarly mounted, are used by miniature-painters and engravers.

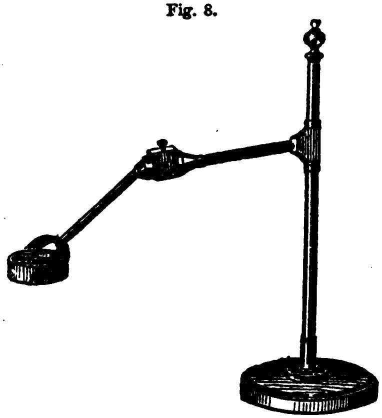
23. Lenses having a focal length of about one inch, set in a horn cell, enlarged at one end like the wide end of a trumpet, the magnitude being made to correspond with the socket of the eye, as represented in fig. 7, are used by watch-makers. The wide end being inserted under the eyebrow, is held in its position by the contraction of the muscles surrounding the eye-ball, and the minute work to be examined, is held within an inch of the lens set in the smaller end of the horn case; if the focal length be an inch, the magnifying power of such a glass, for average eyes, will be ten.

Fig. 7.

Glasses somewhat similarly mounted are used by jewellers, gem-sculptors, and other artists.

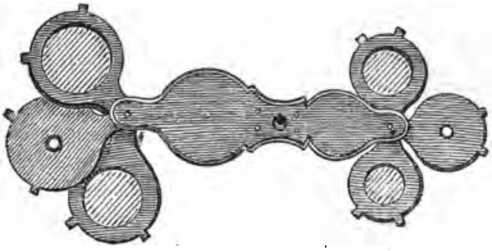
24. To relieve the artisan from the fatigue of holding the magnifier in the eye-socket or in the hand, a stand with a moveable socket is sometimes resorted to, such as that represented in fig. 8. A horizontal arm slides upon a vertical rod, upon which it can be fixed at any desired height by a tightening screw. This arm consists of two joints, connected together by a ball and socket, by which they can be placed at any desired inclination; at the extremity of the lower arm a fork supports a ring-shaped socket, made to receive the magnifier.

Fig. 8.



25. Very convenient pocket magnifiers are mounted in tortoise-shell or horn cases, in the form shown in fig. 9. Lenses of different powers are provided which may be used separately or together; when they are used together, however, the interposition of a diaphragm is necessary to diminish the effects of spherical aberration by cutting off the lateral rays.

Fig. 9.



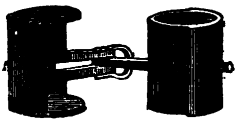
Lenses thus mounted are well fitted for medical use, and for certain researches in natural history.

26. When a higher power is required than that which these common magnifiers afford, a magnifying glass, called from its inventor a Coddington lens, is used with much advantage. To produce such a lens, a solid ball or sphere of glass, about ½ an inch in diameter, is cut round its equator, so as to form round it an angular groove, leaving two spherical surfaces on opposite sides uncut. The angular groove is then filled up with opaque matter, the circular edge of the groove serving as a diaphragm between the two spherical surfaces. A section of such a lens is shown in fig. 10, where A B and A′ B′ are the two spherical surfaces left uncut, and A C A′ and B C B′ the section of the angular groove filled with opaque matter. The course of the rays passing through it from any point such as O, is shown by the lines O *o*, and it will be evident from the

Fig. 10.

mere inspection of the figure, that the effect of the lens upon the rays will be precisely the same, wherever the point O may be placed; this lens, therefore, gives a large field equally well defined in all directions, and since it is no matter in what position it is held, it is very convenient as a hand and pocket glass; it is usually mounted in a small case, such as is shown in fig. 11, which can be carried in the waistcoat pocket.

Fig. 11.



27. Magnifying glasses of low powers, such, for example, as those which range from 5 to 40, may be constructed with much advantage in one or the other of the above forms. When, however, higher powers are necessary, the use of such lenses, with very short focal length, is attended with much practical inconvenience, which has been removed by the use of magnifiers, consisting of two or more lenses combined. The combinations of this kind which are found most efficient, consist of two or three plano-convex lenses, with their convex side towards the eye; these are called doublets and triplets.

28. After what has been explained in our Tract upon Optical Images, the principle upon which these magnifiers depend will be easily understood.

Let E E and D D, fig. 12, represent the two lenses of a doublet, and let *o o* be a small object placed before D D, at a distance from it less than its focal length. According to what has been explained, D D will produce an imaginary image of *o o* at *i i*, more distant from D D than *o o*, so that an eye placed behind D D would receive the rays from *o o*, as if they had diverged from the corresponding points of *i i*.

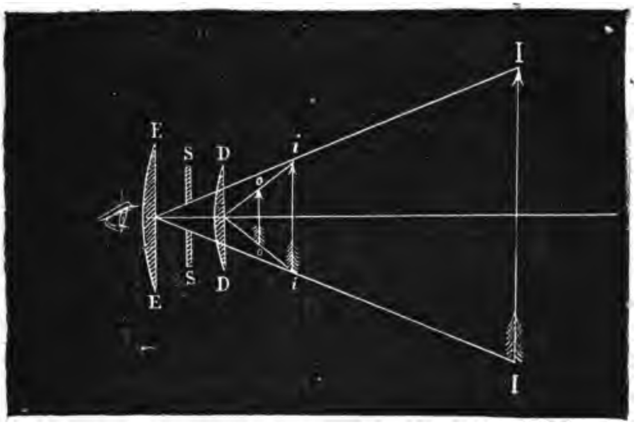
But instead of being received by an eye placed behind D D, these rays are received by the other lens E E; the image *i i* therefore plays the part of an object before the lens E E, and being at a distance from E E less than the focal length of the latter, an imaginary image of *i i* will be produced at I I; the rays, after passing through E E, entering the eye as if they had come from the corresponding points of I I.

To cut off all scattered rays not necessary for the formation of the image, a stop or diaphragm, S S, consisting of a circular disc of metal, with a hole in its centre, is interposed between the two lenses.

29. Such a combination, when high powers are necessary, has several advantages over an equivalent single lens. In the first place, the effect of spherical aberration is much less, and secondly,

the object can be placed at a much greater distance from the anterior lens D D, and can consequently be more conveniently

Fig. 12.

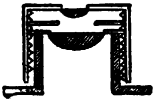


manipulated, if it be desired to dissect it, or to submit it to any other process; it can also be illuminated by a light thrown upon that side of it which is presented to the glass; this could not be done if it were nearly in contact with the glass, which must necessarily be the case by reason of its very short focal length, if a single lens were used.

30. It was recommended by Dr. Wollaston, the inventor of these doublets, to give the two lenses composing them unequal focal lengths, that of E E being three times that of D D.

The lenses are usually set in two thimbles, one of which screws into the other, as shown in fig. 13, so that they can be adjusted as to their mutual distance, so as to produce the best effect. When still higher powers are sought, the lens D D is replaced by two plano-convex lenses, in contact, which taken together play the part of the single lens D D in the doublet; this combination is called the triplet.

Fig. 13.

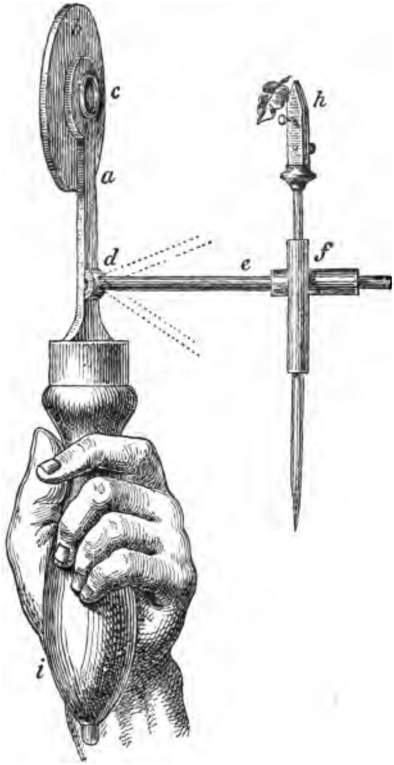


When a very low magnifying power is required, the lenses E E and D D may be separated, by unscrewing.

31. The lenses, whether of a doublet or a triplet, being thus properly mounted, expedients must be adopted to enable the observer to apply them conveniently to the object under examina-

tion. The most simple method of effecting this would be to hold the lens to the eye with one hand, and to present the object before it at the proper distance with the other. But even in this case it would be necessary that the lens should be attached to a convenient handle, and unless the magnifying power were very low, the steadiness necessary to retain the object in the focus could not be imparted to it, and while the observation would be unsatisfactory the fatigue of the observer would be considerable. When high powers are used, every motion of the object is as much magnified as the object itself, and consequently in such cases the most extreme steadiness is indispensable.

Fig. 14.



Whatever be the form of the mounting, therefore, it is necessary that the object should be supported by some piece attached to that by which the doublet itself is supported, so that it may be steadily held in the axis of the lenses, and that its distance from them may be varied at pleasure, by some smooth and easy motion, by which the observer can bring the object to the proper focus.

The means by which these ends have been attained vary according to the use to which the microscope is to be applied, to its cost, the taste and fancy of the observer, and the skill and address of the maker.

One of the most convenient forms of mounting, for a common hand microscope is shown in fig. 14.

The doublet is inserted in a socket *c* made to fit it; the screen *b* protects the eye from the light by which the object is illuminated, an arm *e* is jointed at *d*, so that it can be turned flat against *a*, when the instrument is not in use, and can be inclined to *a*, at any desired angle. This arm being round, a sliding tube *f* is placed upon it, fixed to another tube at right angles to it, in which a vertical rod slides, to the upper end of which is attached a forceps or any other convenient support of the object under examination.

Several doublets or triplets of various powers may be provided, any of which may be inserted at pleasure in the socket *c*.

32. When still greater steadiness is required, and greater bulk and higher price do not form an objection, the arm and socket bearing the doublet are fixed upon a vertical pillar, screwed to a table with proper accessories for adjusting the focus and illuminating the object.

The arrangement adopted in the simple microscopes of Charles Chevalier, shown in fig. 15, p. 97, may be taken as a general example of this class of mounting.

The case in which the instrument is packed serves for its support when in use. A square brass pillar T T, screwed into the top of this case X, has a square groove cut along one of its sides, in which the square rod G is moved upwards and downwards by a rack and pinion R; at the top of this rod, a horizontal arm *a* is attached, at the end of which a socket is provided to receive the doublets; several of which having different powers are supplied with the instrument.

The object under observation is supported on the stage P, firmly attached to the upper end of the square pillar T T; in this stage is a central hole, through which light is projected on its lower surface when the object is transparent, and the quantity of this light is modified by means of an opaque disc D, pierced with holes of different magnitudes.

By turning this disc on its centre, any one of these holes may be brought under the object; when the object is not transparent, the opening in the stage is stopped, and it is viewed by light thrown upon its upper surface.

A square box B, sliding upon the pillar T T, with sufficient friction to maintain it at any height at which it is placed, carries a reflector M, by which light is projected upwards to the opening of the stage P, this light being more or less limited in quantity by the orifice of the diaphragm D, which is presented in its path.

In this instrument the object is brought into focus by moving the arm which carries the doublet up and down, by means of the rack and pinion R, the stage supporting the object being fixed The same effect might be, and is in some microscopes, produced by moving the stage supporting the object to and from the lens: but when the instrument is applied to dissection, it is necessary to keep the subject dissected immoveable, and, therefore, not only to maintain the stage stationary, but to render it so solid and stable that it will bear the pressure of both the hands of the operator while he manipulates the dissecting instruments; on this account the stage is often made larger than is represented in the figure, and supported by a separate pillar.

The arm *a* carrying the doublet is also sometimes fixed in a square socket on the top of the rod G, so that it can be moved to and fro in the socket, while the socket itself can be turned upon the rod G; by this combination of motions, the observer can with great convenience move the lens over every part of the object under examination.

Simple magnifiers, with provisions similar to these, are made by the principal opticians, Messrs. Ross, Leland and Powell, Smith and Beck, Pritchard, Varley, and others.

When the object has not sufficient transparency to be seen by light transmitted through it from below, it may be illuminated by a light thrown upon it from above by a lamp or candle, and condensed, if necessary to obtain greater intensity, by means of a concave reflector or convex lens.

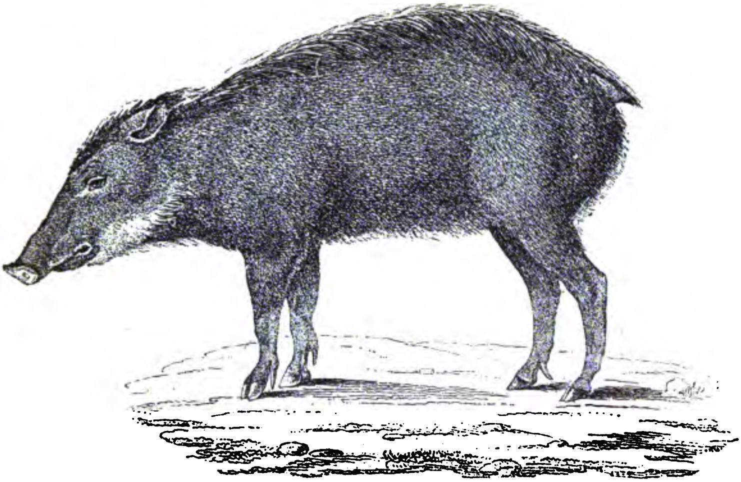


FIG. 26.—THE PECARI, OR SOUTH AMERICAN HOG.

INSTINCT AND INTELLIGENCE.

CHAPTER I.

1. Instinct defined. — 2. Independent of experience or practice. — 3. Sometimes directed by appetite.—4. A simple faculty independent of memory.—5. Instinctive distinguished from intelligent acts.—6. Instinct and intelligence always co-exist.—7. The proportion of instinct to intelligence increases as we descend in the organic chain.—8. Opinions of Descartes and Buffon—Character of the dog.—9. Researches and observations of Frederic Cuvier.—10. Causes of the errors of Descartes, Buffon, Leroy, and Condillac.—11. Degrees of intelligence observed in different orders of animals.—12. Accordance of this with their cerebral development.—13. Opposition between intelligence and instinct.—14. Consequences of defining their limits.—15. Example of instinct in ducklings.—16. In the construction of honeycomb.—17. The snares of the ant-lion.—18. Their mode of construction and use.—19. Spiders' nets.—20. Fishes catching insects.—21. Provident economy of the squirrel.—22. Haymaking by the Siberian lagomys.—23. Habitations constructed by animals.—24. The house of the hamster.—25. The habitation of the mygale, with its door.—26. Habitations of caterpillars.—27. Clothing of the larva of the moth.—28. Dwellings of animals which are torpid at certain seasons.—29. The Alpine marmot—Curious structure of their habitations.—30. Method of constructing them. —31. Singular habits of these animals.—32. Instincts of migration.—33. Irregular and occasional migration.—34. General assembly preparatory to migration.—35. Occasional migration of monkeys.

INSTINCT AND INTELLIGENCE.

1. In contemplating the habits and manners of animals, numerous acts are observed bearing marks of more intelligence and foresight than it is possible to suppose such agents to exercise. Since intelligence, therefore, cannot be admitted as the exciting cause for such actions, they have been ascribed to another power, called INSTINCT, which is defined to be one by which, independent of all instruction or experience, animals are unerringly directed to do spontaneously whatever is necessary for their preservation and the continuance of their species.

2. Instinct, therefore, must be regarded as a simple power or disposition emanating directly from the Creator, and producing its effects, without the intervention of any mental process. These effects, moreover, are susceptible of no modification by experience or repetition. A purely instinctive act is performed with as much facility and perfection at the first attempt as after repetition, no matter how long continued. The new-born infant seizes the mother's breast with its lips, draws the milk from it, and swallows that nourishing fluid—a very complicated physical process—as readily and as perfectly as it does after the daily experience and practice of ten or twelve months. The young bee just emerged from the cell, sets about the highly geometrical process of constructing its complicated hexagonal comb, and accomplishes its work with as much facility and perfection as the oldest inhabitant of the hive.

3. Instinct operates sometimes, but not invariably, by the intervention of physical appetite. Thus animals seek food, and the union of the sexes, not with the purposes which Nature designs to attain by these acts, but for the mere pleasure attending the gratification of appetite and passion. This pleasure is the bait which the Creator throws out to allure them to do what is indispensable for the preservation of the individual and the continuance of the species.

Thus, although animals seek food to satisfy hunger, the act is still instinctive. In the choice of food, that which is hurtful or poisonous is avoided, and that which is nutritious selected. The food which is suitable to the organs of digestion is always that to which the animal directs itself. These organs in some are adapted to vegetable, in others to animal food, and each species accordingly seeks the one or the other. Since it cannot be imagined that these animals are endowed with intelligence by which they are enabled to judge of the qualities of this or that species of aliment, it is clearly necessary to ascribe their acts in choosing always those which are suitable to them, to a power different from and independent of intelligence.

4. While instinct is a simple power, prompting acts apparently

the most complicated, and producing its effects at once in the most perfect manner and without any internal effort on the part of the agent, intelligence, on the contrary, is a faculty consisting of various distinct operations depending on experience and susceptible of indefinite improvement by exercise. The perceptions received from external objects are the data upon which it is exercised. These perceptions are capable of being revived and identified by the faculty called memory. Thus, having once perceived any given object, it is identified upon its recurrence by the consciousness that the perception it produces is the same as that which was formerly produced by it. Thus, objects once seen are known when seen again.

Memory is essential to almost all other acts of intelligence, the most simple of which is that by which the mind infers that any effect which has been once produced will be again reproduced by the same agent under like circumstances; and the oftener such effects are observed to be reproduced, the more strong is the conviction that they will reappear.

5. Instinctive acts are done without any perception or consciousness of their consequences on the part of the agent. Intelligent acts, on the contrary, are performed not only with a consciousness of their consequences, but *because* of that consciousness. They are performed precisely with a view to produce the effects which are known by previous experience to have resulted from them.

6. It must not be supposed that instinct and intelligence cannot coexist, or that the animal endowed with either is necessarily deprived of the other. It is certain, on the contrary, that most animals are more or less gifted with both. In man, constituting the highest link in the chain of animal organisation, the faculty of intelligence predominates in an immense proportion over that of instinct. In passing to the next link, the relation between these faculties undergoes a change so enormous, that naturalists have regarded man not merely as a species of animal, but as an order of organised beings apart, being the sole genus of his order and the sole species of his genus.

7. In descending from link to link downwards along the chain of animal organisation, the play of intelligence is observed to bear a less and less proportion to that of instinct, until we arrive at the last links, where all trace of intelligence is lost, and animal life becomes a mere system of phenomena produced by instinctive impulses.

8. The question of the relative provinces and play of instinct and intelligence in the animal world, has been agitated among philosophers and naturalists from the earliest epochs down to our

own times. Descartes maintained that the inferior animals were mere automata, but that being constructed by Nature, they are incomparably more perfect than any which could be constructed by man. Buffon allowed them sensations, and a consciousness of present existence, but denied them all exercise of thought, reflection, the consciousness of past existence or memory, and the power of comparing their sensations or having ideas. Yet notwithstanding this, in other parts of his works, he admits that a power of memory, active, extensive, and retentive, cannot be denied to certain species. Thus, in his history of the dog, he says that an ardent, choleric, and even ferocious disposition, which renders that animal in the wild state formidable to all around it, gives place in the domestic dog to the most gentle sentiments, the most lively attachments, and the strongest desire to please. The dog, creeping to the feet of its master, places at his disposition its courage, its force, and its talents. It waits his orders merely to execute them; it consults him, interrogates him, supplicates him, understands the slightest signs of his wishes: has all the warmth of sentiment which characterises man, without the light of his reason; has more fidelity, more constancy; no ambition, no selfish interest, no desire of vengeance, no fear save that of its master's displeasure. It is all zeal, all ardour, all obedience. More sensible to the memory of kindness than of injury, it is not disheartened by bad treatment. It submits and forgets, or remembers only the more to attach itself. Far from being irritated by, or flying from him who punishes it, it willingly exposes itself to new trials. It licks the hand which strikes it, offers no remonstrance save the expression of its pain, and disarms the hand which punishes it by patience and submission.*

Thus while Buffon refuses thought to the dog, he admits that he is capable of consulting, interrogating, and supplicating his master, and understanding the signs of his will. But, how, it may be asked, can a dog understand, without understanding? Without the faculty of memory, how can he remember kindness and forget ill-treatment? Buffon, as M. Flourens justly observes, admits as an historian, but he denies as a philosopher, and in spite of his acute understanding, allows his judgment to be influenced by the purpose to which the work on which he is engaged at the moment is directed. As an historian, he has to state facts; and he does so with truth and eloquence. As a philosopher, he has to defend a system; and he closes his eyes on all facts save those which support his hypothesis.

9. During more than a century which elapsed between the

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* "Histoire du Chien," vol. 5, p. 186.

epochs of Descartes and Buffon,* the question of the instinct and intelligence of animals was discussed in the spirit of the ancient philosophy on purely metaphysical grounds. It was with Buffon, and soon afterwards with Leroy, that it began to be placed upon the basis of observation and induction; but the first philosopher who reduced it to a definite form and supported his reasoning by observations systematically pursued was Frederick Cuvier. He proposed to determine the limits of the intelligence of different species; those which separate intelligence generally from instinct; and those in fine by which human intelligence is distinguished from that of inferior animals. These three points being once established, the long vexed question of animal intelligence was presented under a new aspect.

10. When Descartes and Buffon refused intelligence to animals, they did so because they could not accord to them the same faculty of intelligence which characterises the human race. Their error therefore arose from not perceiving or not defining the limit which separates human from animal intelligence.

When Condillac and Leroy, on the contrary, falling into the other extreme, accorded to animals the most elevated intellectual powers, they did so because they overlooked the distinction between instinct and intelligence. When they ascribed to intelligence acts which were prompted by instinct, and therefore executed with a perfection which, if they were the result of intelligence, would require a very elevated degree of that faculty, they were forced to admit in animals the possession of powers in some respects even more elevated than those of the human race.

11. The first observations of Frederick Cuvier indicated the various degrees of intelligence in the different orders of mammifers. Thus he found the highest development of that faculty in the *Quadrumana*, at the head of which stand the chimpanzee and ourang-outang. The second rank was assigned to the *Carnivora*, at the head of which was placed the dog. The *Pachydermata* stand next, with the horse and the elephant at their head; the two lowest ranks consisting of the *Ruminants* and *Rodents*.

12. Now it is important to remark that this classification of mammifers according to their relative intelligence, based upon the direct observation of their manners and habits, is found to be in complete accordance with their cerebral development; the organs of the brain, which in man have been ascertained as being those on which the intellectual functions depend, existing in a less and less state of development as we descend from the Quadrumana to the Carnivora, from the latter to the Pachydermata, and from these successively to the Ruminants and Rodents.

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* Descartes published his "Discours sur la Mèthode" in 1637; and Buffon published the "Discours sur la Nature des Animaux" in 1753.

The reader will find these conclusions verified by many of the examples which will be presently produced, but those who desire a more complete demonstration must have recourse to the numerous and beautiful memoirs of Frederick Cuvier, in which the original observations are recorded.

13. After having established the limits which distinguish the degrees of intelligence of different orders of animals, Cuvier took up the still more important question to fix the limit between intelligence and instinct.

Between these powers there is the most complete opposition. All the results of instinct are blind, necessary, and invariable. All those of intelligence, on the contrary, are optional, conditional, and susceptible of endless modification. The beaver, which builds its hut, and the bird which constructs its nest, act by instinct alone. The dog and the horse, which are educated so as to understand the signification of several words uttered by those who have charge of them, do so by the exercise of intelligence.

All the results of instinct are innate. The beaver builds its hut without having learned to do so. It is urged by a constant and irresistible force. It builds because it cannot help building.

All the results of intelligence arise from experience and instruction. The dog obeys his master, only because he has learned to do so. He is a free agent, and obeys because he wills to obey.

In fine, the results of instinct are particular, while those of intelligence are general. The industry and ingenuity which has excited so much admiration in the beaver, is displayed in nothing except the construction of his hut, while the same degree of attention and thought, which enables the dog to obey his master in one thing, will equally avail him to perform other acts.

14. So long as these two powers of instinct and intelligence were undistinguished one from the other, the manners and habits of animals presented to the contemplation of the observer endless obscurity, and the most perplexing contradiction. While in most actions the superiority of man over other animals is apparent, in many the superiority seems to pass to the side of the brute. This paradox and apparent contradiction disappears, however, when the boundary between instinct and intelligence is clearly marked. Whatever proceeds from intelligence in the lower animals, is incomparably below that which results from the intelligence of man; and on the contrary, all those acts of the lower animals, which, supposing them to result from intelligence, would require a higher degree of that faculty than man possesses, are the mere effects of the blind mechanical power of instinct.*

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* Flourens' "De l'Instinct et de l'Intelligence des Animaux," p. 36.

15. As an example of an act manifestly instinctive, a fact familiar to all who have visited a poultry-yard may be mentioned. When a mixed brood of chickens and ducklings hatched by a hen approach for the first time a pond of water, the ducklings precipitate themselves into the liquid, in spite of the efforts of their adopted mother to prevent them, and contrary to the example of the chickens, with whom they have come into life and from whom they have never been separated. The ducklings who do this may have never before seen water or any individuals of their own species, yet they use their webbed feet as propellers with as much skill as the oldest and most experienced of their race.

16. An example of a much more complicated process, which is manifestly instinctive, is presented by the labours of the bee already mentioned. The comb is a highly geometrical structure, which, if executed under the direction of intelligence, would require not only faculties of a high order, but profound calculation and much experience. Considered in relation to the purposes it is destined to fulfil, it would require the greatest foresight and a thorough knowledge of the whole course of life and organic functions of the species to which the constructors belong. Supposing them to be endowed with the necessary intelligence, the combs could not be constructed without many preliminary trials and partial failures, the necessary perfection being only attainable by slow degrees and by means of a series of experiments. Nothing of the kind however takes place, the complicated structure being produced at once with the greatest facility and in the highest perfection. There are, therefore, here none of the characters of a work directed by intelligence, but all the marks of one prompted by instinct.

17. Although the acts by which animals obtain and select their proper food are undoubtedly instinctive, they are, nevertheless, often attended with circumstances which it would be difficult to explain without the intervention of some degree of intelligence.

Fig. 1.—The Ant-Lion.

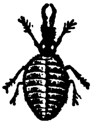

Fig. 2.—Larva of the Ant-Lion.

There is a little insect of the order *Neuroptera* and the family

Myrmeleonidæ, commonly called the *ant-lion*, represented in its natural size in fig. 1, the larva of which is also represented in its natural size in fig. 2. This larva feeds upon ants and other insects, of which it sucks the juice; but as its powers of locomotion are greatly inferior to those of its prey, it would perish for want of nourishment, if Nature had not endowed it with instinctive faculties by which it is enabled to capture by stratagem the animals upon which it feeds.

18. After having carefully surveyed the ground upon which it is about to operate, it commences by tracing a circle corresponding in magnitude with its intended snare. Then placing itself within this circle, and using one of its feet as a spade or shovel, it sets about making an excavation with a tunnel-shaped mouth. It throws upon its head the grains of sand which are digged up with its feet, and by a jerk of its body it flings them to a distance of some inches outside the circle which it has traced, throwing them backwards by a sudden upward movement of the head. Proceeding in this way it moves backwards, following a spiral course, continually approaching nearer to the centre. At length so much of the sand is thrown out that a conical pit is formed, in the bottom of which it conceals itself, its mandibles being the only parts which it allows to appear above the surface. If in the course of its work it happens to encounter a stone, the presence of which would spoil the form of the pitfall, it first pays no attention to it, and goes on with its labour. After having finished the excavation, however, it returns to the stone, and uses every effort to detach it, to place it on its back and throw it out of the pit. If it do not succeed it abandons the work, and departs in search of another locality, where it recommences with admirable patience a similar excavation.

These pitfalls, fig. 3, when completed, are generally about three inches in diameter and two in depth; and when the slope of the sides has been deranged, — which almost always happens when an insect falls into it,—the ant-lion immediately sets about repairing the damage.

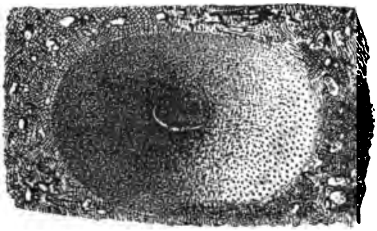
Fig. 3.—Pitfall of an Ant-Lion.

When an insect happens to fall into the pit, the ant-lion instantly seizes it and puts it to death, and the fluids having been all sucked out, its dry carcass is treated exactly like the grains of sand, and jerked out of the hole. If, however, as often happens, an insect who has the misfortune to fall from the brink of the precipice should recover itself, and escaping the murderous jaws of its enemy regain the summit, the latter immediately begins to throw up more sand, whereby not only is the hole made deeper, but its sides are rendered more precipitous, and the flying insect is often hit by the masses thus projected, and brought down again to the bottom.

19. Certain spiders spread snares still more singular. The web which these animals spread is destined to catch the flies and other insects upon which they prey. The disposition of the filaments composing this web varies with different species, but is often of extreme elegance.

20. There are certain fishes which feed upon insects that are not inhabitants of the water, and who resort to expedients, bearing marks of great ingenuity, to capture their prey. Thus, a species called the *Archer*, which inhabits the Ganges, feeds on insects which are accustomed to light upon the leaves of aquatic plants. The fish, upon seeing them, projects drops of water upon them with such sure aim, that it seldom fails to make them fall from the leaf into the water, when it seizes upon them. As the near approach of the fish would alarm the insect and cause its flight, this species of liquid projectile is usually launched from a distance of several feet, where the insect cannot see its enemy.

21. Certain species feed upon natural products, which are only to be found at particular seasons of the year; and in all such cases Nature prompts them, during their proper harvest, to collect and store up such a quantity of food as may be sufficient for their support, until the ensuing season brings a fresh supply. The common squirrel (fig. 4.) presents an example of this instinct. During the summer these active little creatures collect a mass of nuts, acorns, almonds, and other similar products, and establish their storehouse usually in the cavity of a tree. They have the habit of providing several of these magazines

Fig. 4.—The Common Squirrel.

in different hiding-places cunningly selected; and in winter, when the scarce season arrives, they never fail to find their stores, even when they are overlaid with snow. It is remarkable that this impulse to hide their food does not cease with the necessity for it, for they take the same care of the residue unconsumed upon the return of the ensuing season.

22. Another rodent, called by naturalists the *Lagomys pica*, which bears a close resemblance to the common rabbit, and inhabits Siberia, is endowed with an instinct still more remarkable, since it not only collects in autumn the herbage necessary for its sustenance during the long winter of that inhospitable country, but it actually makes hay exactly as do our agriculturalists. Having cut the richest and most succulent herbs of the field, it spreads them out to dry in the sun; and this operation finished, it forms them into cocks or ricks, taking care so to place them that they shall be in shelter from the rain and snow. It then sets about excavating a tunnel leading from its own hole to the bottom of these ricks, so that it may have a subterranean communication between its dwelling and its hay-yard; taking care, moreover, that, the hay being gradually cut from the interior of each stack, the protection provided by the thatching of the external surface will not be disturbed.

23. Another form of that particular instinct the object of which is the preservation of the individual, is manifested in the art, with which certain species construct for themselves a suitable dwelling. In executing all the operations, often very complicated, directed to this purpose, their labours are invariably marked by the same general routine, although the operative by whom the work is executed has never before witnessed a similar process, and is aided by neither direction, plan, nor model.

We have already mentioned the structure of the honeycomb as an example of this, but the insect world abounds with others not less interesting.

The silkworm constructs for itself, with the delicate threads which it spins, a cocoon, in which it encloses itself, to undergo in safety its metamorphosis and to become a butterfly. The rabbit, in like manner, burrows for itself a dwelling, and the beaver constructs those little houses which have rendered it so celebrated. We shall, on another occasion, return to architectural instinct, in noticing the labours executed in common by animals which live in societies.

24. The hamster (fig. 5) is a little animal of the class of rodents, bearing a close resemblance to the common rat. It inhabits the fields throughout Europe and Asia, and inflicts much injury on the farmer and agriculturalist. This animal constructs for itself

a subterranean house, consisting of several rooms connected together by corridors. The dwelling has two communications with the surface, one consisting of a vertical shaft, by which the animal makes its entrances and exits; the other is an inclined shaft, merely used for the purposes of construction, the animal extruding through it the earth excavated in the formation of its habitation. One of the rooms is furnished, as the bedroom of the owner, with a couch of clean, dry grass, and is otherwise neatly kept. The others are used as store-rooms for the winter stock of provisions, which are amassed there in considerable quantities.

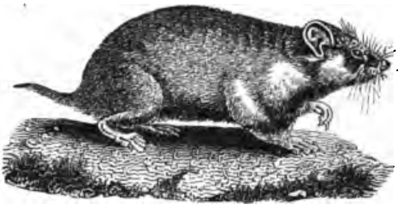

Fig. 5.—The Hamster.

The form of the store-rooms is nearly spherical, and their diameter from 8 to 10 inches.

The female, who never lodges with the male, usually provides several of these vertical entrances to her habitation, with a view to give easy means of entrance to her young, when they are pursued by any enemy, and obliged precipitately to take refuge in their dwelling.

The number of store-rooms which they provide being determined by their stock of provisions, they are excavated in succession, when one is filled the animal beginning to make another.

The room which the female constructs as a nursery for her young ones never includes provisions. She brings there straw and hay to make beds for them. Two or three times a year she has five or six younglings, which she nurses for about six weeks, at which age she banishes them from her dwelling to provide for themselves. The depth of the dwelling varies with the age of the animal, the youngest making it at about the depth of a foot. Each successive year the depth is increased, so that the vertical shaft leading to the den of the old hamster often has a depth of more than five feet, the whole habitation, including dwelling-rooms, store-rooms, and communicating corridors, occupying a space having a diameter of 10 or 12 feet.

25. Certain spiders, known to zoologists by the name of *mygales*, execute works similar to those of the hamster, but much more complicated, for not only do they construct a vast and commodious habitation, but they place at its entrance a *door*, mounted upon

hinges (fig. 6). For this purpose the animal excavates in the ground a sort of cylindrical shaft three or four inches deep, and coats its sides with a tenacious plaster. It then fabricates a door, by uniting alternately layers of plaster and vegetable filaments. This trap-door is made exactly to fit the mouth of the shaft, to which it is hinged by cementing some projecting filaments against the upper edge of the plastered surface. The external surface of this trap-door is rough, and in its general appearance differs little from the surrounding ground. The inside surface, however, is smooth and nicely finished. On the side opposite to the hinge there is a row of little holes, in which the animal introduces its claws to bolt the door when any external enemy seeks to force it open.

Fig. 6.—Nest of the Mygale.

26. It is, however, among the countless species of insects that we find the most curious and interesting processes adopted for the construction of habitations. Many species of caterpillars construct houses by rolling up leaves and tying them together by threads spun by the animal itself. In the gardens, nests of this kind are everywhere to be seen, attached to the leaves of flowers and bushes. It is in this way that the caterpillar of the nocturnal butterfly, the *Tortrix viridana*, forms its nest (fig. 7).

27. Other insects construct habitations for themselves with the filaments of woollen stuff, in which they gnaw holes. Among these is the well-known larva of the common moth, popularly miscalled a worm, which is found to be so destructive to articles of furniture and clothing. With the woolly filaments which it thus cuts from the cloth, the caterpillar constructs a tube or sheath, which it continually lengthens as it grows. When it finds itself becoming too bulky to be at ease in this dwelling, it cuts it open along the side, and inserts a piece, by which its capacity is increased.

Fig. 7.—Nest of Tortrix Viridana.

28. Certain animals, which pass the cold season in a state of lethargy, not only prepare for themselves a suitable retreat, and a soft and comfortable bed, but when they become sensible of the

drowsiness which precedes the commencement of their periodical sleep, they take care to stop up the door of their house, as if they could foresee that a long interval must elapse before they shall want to go out, and that the open door would not only expose them to cold, but might give admission to dangerous enemies.

29. The alpine marmots supply examples of these curious manners.

Fig. 8.—Alpine Marmot.

These animals usually establish their dwellings upon the face of steep acclivities, which look to the south or the east; they assemble in large numbers for the excavation of these dwellings by their common labour. The form of their dens is that of the letter Y placed on its side, thus -<, the tail being horizontal, and one of the two branches being inclined upwards, and the other downwards. The cavity, which forms the tail of the Y, is the dwelling-room. It is carpeted with moss and hay, of which the animal makes an ample provision in summer. The upward branch leads to the door of the dwelling, and supplies the means of exit and entrance to the inhabitants. The descending branch is used for the discharge of ordure, and all other offal, the removal of which is necessary to the cleanliness of the house.

30. Buffon says, that in the construction of these dwellings, the animals observe a curious division of labour: some cut the grass, others collect it in heaps, and others, lying on their backs with their legs upwards, convert themselves into a sort of sledge, upon which the grass is heaped by the others, being kept together by the upright legs of the prostrate animal, just as hay is retained upon a farm-cart by the poles fixed at its corners. The animal lying thus is dragged by the tail by the others, to the mouth of the dwelling in which the grass is deposited.

The latter part of this statement is however called in question by some naturalists.

31. The marmots pass the greater part of their lives in these dens. They remain there during the night and generally during bad weather, coming out only on fine days, and even then not departing far from their dwelling. While they are thus abroad feeding and playing upon the grass, one of the troop, posted on a neighbouring rock, is charged with the duty of a sentinel, observing carefully the surrounding country. If he should perceive approaching danger, such as a hunter, a dog, or a bird of prey, he immediately gives notice by a long continued whistling or hissing noise, upon which the whole troop instantly rush to their hole.

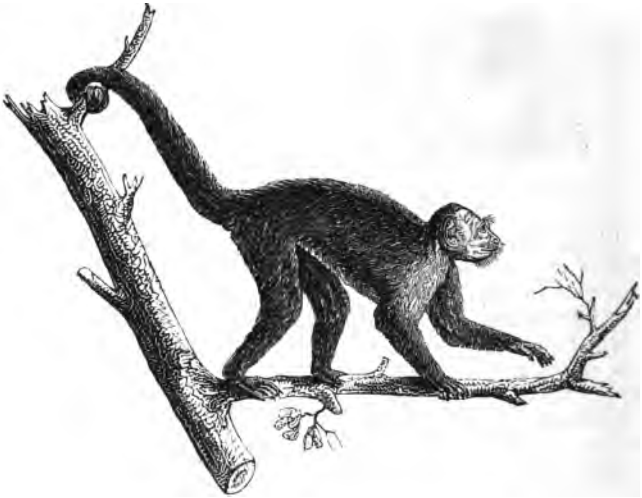

Fig. 9.—The White-throated Sajou.

32. There is another instinct worthy of notice, the object of which is always the preservation of the individual, and sometimes that of the species, which determines certain animals at particular epochs to undertake long voyages. These movements of migratory animals, as they are called, are sometimes periodic, being determined by the vicissitudes of the seasons, the animals being driven either from higher latitudes to lower by extreme cold, or from lower to higher by extreme heat. In other cases the migration is determined by the care of providing for its young; the animal migrating to localities where the food for its offspring abounds, and whence after depositing its eggs it departs

to places more conformable to its own habits and wants. Thus, the migration to and fro fulfils at once the double purpose of providing for the preservation of the species and that of the individual.

33. Where the migration is irregular, and the voyage not long, the movement is prompted by the necessity of seeking a locality where the proper nourishment of the animal is more abundant. In such cases, the animal having exhausted the supplies of a particular district, departs in quest of another, and does not voyage further than is necessary for that object.

Fig. 10.—The Maki.

34. Whatever be the motive which may prompt such voyages, they are almost invariably preceded by a general meeting, having all the appearance of a concerted one, composed of all the individuals of the species which inhabit the locality where it takes place. When the purpose of the voyage is change of climate, they do not wait until they are driven forth by an undue

temperature, but anticipate this change by an interval more or less considerable; nor do they, as might be supposed probable, suffer themselves to be driven by degrees, from place to place, by the gradually increasing inclemency of the season. It would appear that they consider such a frequent change of habitation incompatible with their well-being, and instead of a succession of short voyages, they make at once a long one, which takes them into a climate from which they will not have occasion to remove until the arrival of the opposite season.

35. The monkeys, which abound in such vast numbers in the forests of South America, present an example of irregular migration. When they have devastated a district, they are seen in numerous bands bounding from branch to branch, in quest of another locality more abundant in the fruits which nourish them; and after the lapse of another interval, they are again seen in motion, the mothers carrying the young upon their backs and in their arms, and the whole troop giving itself up to the most noisy demonstrations of joy.

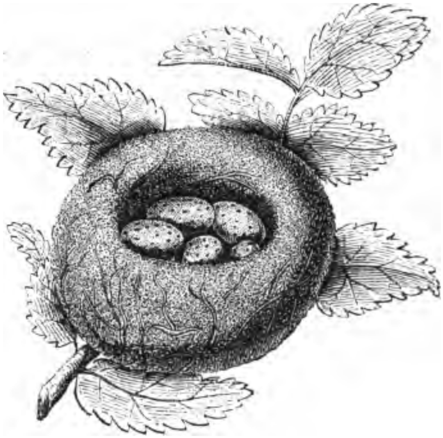

FIG. 19.—NEST OF THE GOLDFINCH.

INSTINCT AND INTELLIGENCE.

CHAPTER II.

36. Migration of the lemmings.—37. Vast migration of field-mice of Kamtschatka.—38. Instincts conservative of species stronger than those conservative of individuals.—39, 40. Instincts of insects for the preservation of their posthumous offspring.—41. 42. Transformations of insects—Precautions in the depositions of eggs.—43. Habitation constructed by liparis chrysorrhea for its young.—44. Examples mentioned by Reaumur and Degeer.—45. Expedients for the exclusion of light from the young.—46. Example of the common white butterfly.—47. Manœuvres of the gadfly to get its eggs into the horse's stomach.—48. The ichneumon.—49. Its use in preventing the undue multiplication of certain species.—50. Its form and habits.—51. The nourishment of its larvæ.—52. The sexton beetle.—53. Their processes in burying carcasses. — 54. Anecdote of them related by Strauss.—55. Singular anecdote of the gymnopleurus pilularius.—56. Such acts indicate reasoning.—57. Anecdote of a sphex told by Darwin.—58. Indications of intelligence in this case.—59. Anecdote of a sexton beetle related by Gleditsch.—60. Indications of reason in this case.—61. Anecdote of ants related by Reaumur.—62. Anecdote of ants related by Dr. Franklin.—63. Anecdote of the bee related by Mr. Wailes. — 64. Anecdote of the humble bee by Huber. — 65.

Memory of insects.—66. Recognition of home by the bee.—67. Singular conduct of the queen.—68. Rogers's lines on this subject.—69. Error of the poet.—70. Anecdote of bees by Mr. Stickney.—71. Instinct of the pompilides.—72. The carpenter bee.

36. IRREGULAR migrations, which are supposed to be in general determined by an instinctive presentiment of an approaching inclement season, are undertaken by small animals called lemmings, which have a close analogy to rats, and which inhabit the mountainous districts of Norway and the Frozen Ocean. These animals live in burrows, in which, like other similar species, they excavate rooms sufficiently spacious, in which they bring up their family. Their food consists in summer of herbs, and in winter of lichens. They lay up no store, however, and collect their supplies from day to day. By an inexplicable instinct, they have a foreknowledge of a rigorous winter, during which the frozen ground would not allow them to collect their food in the country they inhabit. In such case, they emigrate in immense numbers, going to more favoured climates. This surprising presentiment of the character of the season has been frequently observed in this species. It was especially noticed in 1742. During that winter the season was one of extraordinary severity in the province of Umea, though much more mild in that of Lula, of which nevertheless the latitude is higher. It was remarked, on this occasion, that the lemmings emigrated from the former province, but not from the latter.

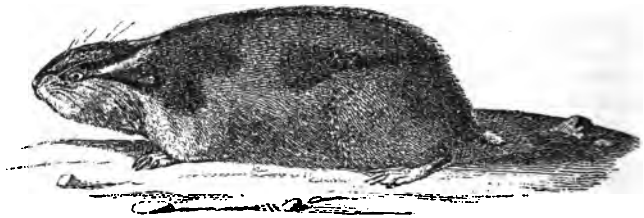

Fig. 11.—The Lemming.

On the occasions of such emigrations, countless numbers of troops of these animals, sometimes descending from the mountains, advance in close columns, always maintaining one direction, from which they never allow themselves to be turned by any obstacle, swimming across rivers wherever they encounter them, and skirting the rocks wherever they cannot climb over them. It is more especially during the night that these legions continue their march, reposing and feeding more generally during the day.

Although great numbers perish during the voyage, they nevertheless do immense damage to the districts over which they pass, destroying all the vegetation which lies in their way, and even turning up the ground, and consuming the fresh sown seed. Happily for the Lapland and Norwegian farmers, the visits of these animals are rare, seldom occurring more than once in ten years.

37. Such migrations, however, are much more frequently periodical, being determined, as already stated, by the change of seasons. Thus, it is found that in spring, immense legions of a little field-mouse, which inhabits Kamtschatka, depart from that country and direct their course towards the west. These animals, like the lemmings, proceeding constantly in one direction, travel for hundreds of leagues, and are so numerous that even after a journey of twenty-five degrees of longitude, in which a considerable proportion of their entire number must be lost, a single column often takes more than two hours to pass a given point. In the month of October they return to Kamtschatka, where their arrival constitutes a fête among the hunters, as they never fail to bring in their train a vast number of carnivorous animals, which supply furs in abundance to the inhabitants of these regions.

38. Nature seems even more sedulous for the preservation of the species than for that of the individual, and we find accordingly the instincts which are directed to the former purpose more strongly developed even than those of self-preservation. The animal world presents innumerable examples of this in the measures which nearly all species adopt with a view to the care of their young. The bird continues often for weeks to sacrifice all her own pleasures, and sits upon her eggs almost immovably. Before these eggs are laid she constructs with infinite labour and art a place in which she may with safety deposit them, and where the young which are destined to issue from them may be sheltered, protected, and fed by her until they have attained the growth and strength necessary to enable them to provide food and shelter for themselves.

39. The same instinct is manifested in a still more striking manner by insects. Many of these die immediately after they have laid their eggs, and consequently do not survive to see their young, of whose condition and wants therefore they can have no knowledge whatever by observation or experience. Their beneficent Maker has, however, taught them to provide as effectually for the security and well-being of their posthumous offspring, as if they had the most complete knowledge of their condition and wants. The effects of this instinct are so much the more remark-

able, as in many cases the young in their primitive state of larva inhabit an element and are nourished by substances totally different from those which are proper to their parent.

The instinct which guides certain animals to confer upon their young a sort of education, developing faculties and phenomena having a close analogy to those manifested in the conduct and operations of our own minds, never fails to excite as much astonishment as admiration, and teaches, more eloquently than words, how much above all that man can imagine or conceive, that power must be which has created so many wonders.

40. But the acts which manifest in the most striking manner the play of the instinctive faculty, are those already referred to by which insects, in the deposition of their eggs, adopt such precautions as are best calculated for the preservation of the young, which are destined to issue from these eggs when the provident mother is no more.

41. To comprehend fully this class of acts, it will be necessary to remind the reader that insects in general, before they attain their perfect state, pass through two preliminary stages, in which their habits, characters, and wants are totally different from those of the parent. The first stages into which the animal passes in emerging from the egg, is that of the *larva*, or grub; and the second, that of the *nymph*, or *pupa*.

Not only is the form and external organisation of the larva different from that of the insect into which it is destined to be ultimately transformed, but it is generally nourished by a different species of food, and often lives in a different element. Thus, while the perfect insect feeds upon vegetable juices, its larva is often voraciously carnivorous. While the perfect insect lives chiefly on the wing in the open air, the larva is sometimes aquatic, sometimes dwells on the hairs, or in the integuments, or even in the stomach or intestines of certain animals. The insect, therefore, cannot be imagined to know, from any experience, what will be the natural wants of the young which are destined to emerge from her eggs.

In many cases, any such knowledge on her part is still more inconceivable, inasmuch as the mother dies before her young break the shell. Nevertheless, in all cases, this mother, in the deposition of her eggs, is found to adopt all the measures which the most tender and provident solicitude for her young can suggest. If her young, for example, are aquatic, she deposits her eggs near the surface of water. If they are destined to feed upon the flesh or juices of any species of animal, she lays not only upon the particular animal in question, but precisely at those parts where the young shall be sure to find their proper nourishment.

If they are destined to feed upon vegetable substances, she deposits her eggs on the particular vegetables, and the particular parts of these vegetables which suit them. Thus, some insects lay their eggs upon the leaves of a certain tree, others in the bark of wood. Others again deposit them in the grain or seed of certain plants, and others in the kernel of certain fruits; each and all selecting precisely that which will afford suitable food to the larva when it breaks the shell.

42. But the care of the tender mother does not terminate here. As though she were aware that she will not herself be present to protect her offspring from the numerous enemies which will be ready to attack and devour it, she adopts the most ingenious expedients for its protection. With this view she envelops her eggs in coverings, which effectually conceal them from the view of the enemies to whose attack they would be exposed. In case the young should be susceptible of injury from the inclemency of the atmosphere, she wraps up the eggs in warm clothing, in which the young larva finds itself when it emerges from them.

43. Some species, such, for example, as the Liparis Chrysorrhea, envelop their eggs in a waterproof covering made of fur taken from their own bodies. They begin by forming with it a soft bed upon the surface of a branch, upon which they deposit several layers of eggs, which they then surround with more fur; and when all are laid, they cover them up with the same fur, the filaments of which, however, are differently disposed. The hairs which form the inside of the nest are arranged without much order, but, on the contrary, those which form its external covering are artfully arranged like the slates of a house, in such a manner that the rain which falls on them must glide off. When the mother has finished her work, which occupies her from twenty-four to forty-eight hours, her body, which before was invested with a clothing of rich velvet, is now altogether stripped, and she expires.

The females who thus provide for the protection of their young, often have the extremity of their bodies furnished with a great quantity of fur destined for this use.

44. Reaumur found one day a nest of this kind, but still more remarkable in its structure. The eggs were placed spirally round a branch, and covered with a thick and soft down, each hair of which was horizontal, which he described as resembling a fox's tail.

Degeer observed a proceeding, similar to those described above, with certain species of aphides, which cover their eggs with a cotton-like down, stripped from their own bodies by means of their hind-feet; but in this case the eggs were not enclosed in a common bed, but each in a separate covering.

45. These precautions seem to be intended not only to protect the eggs from wet and cold, but also to shade them from too strong a light, which would be fatal to the young they contain. It is doubtless for the same purpose that so many insects attach their eggs to the lower in preference to the upper surface of leaves, those which are placed on the upper surface being generally more or less opaque.*

46. The common white butterfly feeds upon the honey taken from the nectary of a flower, but her larva, less delicate and more voracious, devours the leaves of cabbage-plants. When we see, therefore, this insect flying about and alighting successively upon various plants, we imagine erroneously that she is in quest of her own food, when in reality she is searching for the plant whose leaves will form the proper nourishment for her future offspring. Having found this, and having carefully ascertained that it has not been pre-occupied by another of her species, she lays her eggs upon it and dies.

47. The young of the Gadfly (*Œstrus Equi*) are destined to live in the stomach of a horse. This being stated, it may well be asked how the insect fulfils that duty already described, which consists in depositing the eggs upon the very spot where the young will find their food; for it can scarcely be imagined that the winged insect will fly down a horse's throat to lay in its stomach. Yet the parent accomplishes its object in a manner truly remarkable. Flying round the animal, she lights successively many times upon its coat, depositing several hundreds of her little eggs at the extremity of the hairs, to which she glues them by a liquid cement secreted in her body. This, however, would obviously fail to accomplish the purpose of supplying the young with their proper food, only to be found in the horse's stomach, to which, therefore, it is indispensable that the eggs should be transferred. Marvellous to relate, this transfer is made by the horse himself, who, licking the parts of his hide to which the eggs are attached, takes them, or the grubs evolved from them, if they have been already hatched, upon his tongue, and swallows them mixed with saliva; thus conveying them to the only place where they can find their proper food!

But it may be objected, that by this process no eggs or grubs would find their way to the stomach, save those which might chance to be deposited upon those particular parts of the horse's body which it is accustomed to lick. There is, however, no chance in the affair; for the insect, guided by an unerring and beneficent power, and as if foreseeing the inevitable loss of such of

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* Lacordaire, Int. Ent., vol i., p. 29.

her young as might be deposited elsewhere, takes care to lay her eggs on those spots only, such as the knees and shoulders, which the horse is sure to lick!

48. Ichneumon was a name given to a certain species of quadrupeds, which were erroneously supposed to deposit their young upon the bodies of crocodiles, the entrails of which they gradually devoured. The name was transferred by Linnæus to a vast tribe of insects, whose young are destined to feed upon the living bodies of other insects, on which accordingly the mother deposits her eggs. The ichneumons were called by some naturalists *Muscæ vibrantes*, from the constant vibration of their antennæ, by which they were supposed, in some unknown manner, to acquire a knowledge of the insects which would be fit food for their young. This supposition is, however, clearly erroneous, inasmuch as many species do not manifest this vibratory motion.

49. The ichneumons are agents of vast importance in the economy of nature, by checking the too rapid increase of certain species, such as the caterpillars of butterflies and moths, of which they destroy vast numbers. The purpose of nature in this is unmistakeably manifested by the fact, that the ichneumons increase in proportion to the increase of the species they are destined to destroy. Thus Nature maintains the equilibrium in the organic world as much by the operation of the destructive, as by that of the reproductive principle.

50. The ichneumon is a four-winged fly (fig. 12), which takes no other food than honey; and the great object of the female is to discover a proper nidus for her eggs. In search of this she is in constant motion. Is the caterpillar of a butterfly or moth the appropriate food for her young? You see her alight upon the plants where they are most usually to be met with, run quickly over them, carefully examining every leaf, and having found the unfortunate object of her search, inserts her sting into its flesh, and there deposits an egg. In vain her victim, as if conscious of its fate, writhes its body, spits out an acid fluid, menaces with its tentacula, or brings into action the other organs of defence with which it is provided. The active ichneumon braves every danger, and does not desist until her courage and address have insured subsistence for one of her future progeny. Perhaps, however, she discovers, by a sense, the existence of which we perceive, though we have no conception of its nature,

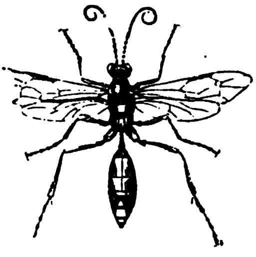

Fig. 12.—The Ichneumon.

that she has been forestalled by some precursor of her own tribe, that has already buried an egg in the caterpillar she is examining. In this case she leaves it, aware that it would not suffice for the support of two, and proceeds in search of some other yet unoccupied. The process is, of course, varied in the case of those minute species, of which several, sometimes as many as 150, can subsist on a single caterpillar. The ichneumon then repeats her operation, until she has darted into her victim the requisite number of eggs.

51. The larvæ hatched from the eggs thus ingeniously deposited, find a delicious banquet in the body of the caterpillar, which is sure eventually to fall a victim to their ravages. So accurately, however, is the supply of food proportioned to the demand, that this event does not take place until the young ichneumons have attained their full growth, when the caterpillar either dies, or, retaining just vitality enough to assume the pupa state, then finishes its existence; the pupa disclosing not a moth or a butterfly, but one or more full-grown ichneumons.

In this strange and apparently cruel operation one circumstance is truly remarkable. The larva of the ichneumon, though every day, perhaps for months, it gnaws the inside of the caterpillar, and though at last it has devoured almost every part of it except the skin and intestines, carefully all this time *avoids injuring the vital organs*, as if aware that its own existence depends on that of the insect on which it preys! Thus the caterpillar continues to eat, to digest, and to move, apparently little injured, to the last, and only perishes when the parasitic grub within it no longer requires its aid. What would be the impression which a similar instance amongst the race of quadrupeds would make upon us? If, for example, an animal—such as some impostors have pretended to carry within them—should be found to feed upon the inside of a dog, devouring only those parts not essential to life, while it cautiously left uninjured the heart, arteries, lungs, and intestines, should we not regard such an instance as a perfect prodigy, as an example of instinctive forbearance almost miraculous?*


Fig. 13.—The Sexton-Beetle.

52. The sexton-beetle, or Necrophorus (fig. 13), when about to deposit its eggs, takes care to bury with them the carcass of a mole or some other small quadruped; so that the young, which, like the

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* Kirby, Int., vol. i., p. 288.

parent, feed upon carrion, the moment they come into existence, may have an abundant provision of nourishment.

53. The measures which these insects take to obtain and keep the carcasses upon which they feed, and which, as has been just observed, also constitute the food of their offspring, are very remarkable. No sooner is the carcass of any small dead animal discovered, such as a bird, a mole, or a mouse, than the sexton-beetles make their appearance around it to the number generally of five or six. They first carefully inspect it on every side, apparently for the purpose of ascertaining its dimensions, its position, and the nature of the ground on which it reposes. They then proceed to make an excavation under it, to accomplish which some partially raise the body, while others excavate the earth under the part thus elevated; the operation being performed with the fore legs. By the continuance of this process, going round the body, they gradually make a grave under it, into which it sinks; and so rapid is the process of excavation, that in a few hours the body is deposited in a hole ten or twelve inches deep. The males co-operate in this labour, and after it is accomplished, the female deposits her eggs upon the carcass.

Fig. 14.—The Necrophorus Hydrophilus.

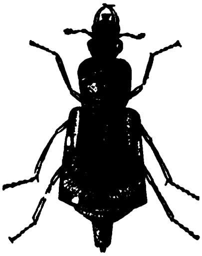

Fig. 15.—The Marine Necrophorus.

54. Clarville * relates that he had seen one of these insects who desired thus to bury a dead mouse, but finding the ground upon which the carcass lay too hard to admit of excavation, it sought the nearest place where the soil was sufficiently loose for that purpose, and having made a grave of the necessary magnitude and depth, it returned to the carcase of the mouse, which it endeavoured to push towards the excavation; but finding its strength insufficient and its efforts fruitless, it flew away. After some time it returned accompanied by four other beetles, who assisted it in rolling the mouse to the grave prepared for it.

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* Cited by Strauss, Considérations Générales, p. 389.

55. A similar anecdote is related of a sub-genus of the Lamellicornes, called the *Gymnopleurus pilularius*, an insect which deposits its eggs in little balls of dung. One of these having formed such a ball, was rolling it to a convenient place, when it fell into a hole. After many fruitless efforts to get it out, the insect ran to an adjacent heap of dung, where several of its fellows were assembled, three of whom it persuaded to accompany it to the place of the accident. The four uniting their efforts, succeeded in raising the ball from the hole, and the three friends returned to their dunghill to continue their labours.*

56. It is difficult, if indeed it be possible, to explain acts like these by mere instinct, without the admission of at least some degree of the reasoning faculty, and some mode of intercommunication serving the purpose of language. If such acts were common to the whole species and of frequent recurrence, it might be possible to conceive them the results of the blind impulses of instinct; but being exceptional, and the results of individual accident, they are deprived of all the characters with which by common consent instinct is invested. On the contrary, there are many circumstances connected with this, which indicate a surprising degree of reason and reflection. Thus, when the insect goes to seek for assistance, it does not bring back, as it might do, from the swarm engaged on the dunghill, an unnecessary number of assistants. It appears to have ascertained by its own fruitless efforts how many of its fellows would be sufficient to raise the dung-ball. To so many and no more it imparts its distress and communicates its wishes; and how can it accomplish this unless we admit the existence of some species of signs, by which these creatures communicate one with another?

57. Darwin relates, that walking one day in his garden, he perceived upon one of the walks a sphex, which had just seized a fly almost as large as itself. Being unable to carry off the body whole, it cut off with its mandibles the head and the abdomen, only retaining the trunk, to which the wings were attached. With these it flew away; but the wind acting upon the wings of the fly, caused the sphex which bore it to be whirled round, and obstructed its flight. Thereupon the sphex again alighted upon the walk, and deliberately cut off first one wing and then the other, and then resumed its flight, carrying off its prey.

58. The signs of intelligence as distinguished from instinct are here unequivocal. Instinct might have impelled the sphex to cut off the wings of the fly before attempting to carry it to its nest, supposing the wings not to be its proper food; and if the head

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* Illiger's Entomological Magazine, vol. i., p. 488.

and abdomen of all flies captured and killed by the sphex were cut off, the act might be explained by instinct. But when the fly is small enough to allow the sphex to carry it off whole, it does so, and it is only when it is too bulky and heavy that the ends of the body are cut off, for the obvious purpose of lightening the load. With respect to the wings, the detaching them was an afterthought, and a measure not contemplated until the inconvenience produced by their presence was felt. But here a most singular effort of a faculty to which we can give no other name than that of reason, was manifested. The progress of the sphex through the air was obstructed by the resistance produced by the wings of the fly which it carried. How is it conceivable that upon finding this, and not before, the sphex should suspend its progress, lay down its load, and cut off the wings which produced this resistance, if it did not possess some faculty by which it was enabled to connect the wings in particular, rather than any other part of the mutilated body of the fly, with the resistance which it encountered, in the relation of cause and effect? To such a faculty I know no other name that can be given than that of reason, although I readily admit the difficulty of ascribing such an intellectual effort.

59. Gleditsch [*] relates that one of his friends desiring to dry the body of a toad, stuck it upon the end of a stick planted in the ground, to prevent it from being carried away by the sexton-beetle, which abounded in the place. This, however, was unavailing. The beetles having assembled round the stick, surveyed the object and tried the ground, deliberately applied themselves to make an excavation around the stick; and having undermined it, soon brought it to the ground, after which they not only buried the carcase of the toad, but also the stick itself.

60. Now this proceeding indicates a curious combination of circumstances which it appears impossible to explain without admitting the beetles to possess considerable reasoning power and even foresight. The expedient of undermining the stick can only be explained by their knowledge that it was supported in its upright position by the resistance of the earth in contact with it. They must have known, therefore, that by removing this support, the stick, and with it the toad, would fall. This being accomplished, it may be admitted that instinct would impel them to bury the toad, but assuredly no instinct could be imagined to compel them to bury the stick; an act which could be prompted by no conceivable motive except that of concealing from those

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[*] Phys. Bot. Œcon. Abhand., vol. iii., 220.

who might attempt to save the body of the toad from the attacks of the beetles, the place where it was deposited.

61. Among the innumerable proofs that animals are capable of comparing, and to a certain extent generalising their ideas, so as to deduce from them at least their more immediate consequences, and thereby to use experience as a guide of conduct, instead of instinct, Reaumur [*] mentions the case of ants, which being established near a bee-hive, fond as they are of honey, never attempt to approach it so long as it is inhabited; but if they happen to be near a deserted hive, they eagerly rush into it, and devour all the honey which remains there. How can we account for this abstinence from the inhabited hive, in spite of the strong appetite for its contents, so plainly manifested in the case of the empty one, if not by the knowledge that on some former occasion a rash attack upon an inhabited hive was visited by some terrific vengeance on the part of the bees?

62. Dr. Franklin was of opinion that ants could communicate their ideas to each other; in proof of which he related to Kalm, the Swedish traveller, the following fact. Having placed a pot containing treacle in a closet infested with ants, these insects found their way into it, and were feasting very heartily when he discovered them. He then shook them out, and suspended the pot by a string from the ceiling. By chance one ant remained, which, after eating its fill, with some difficulty found its way up the string, and thence reaching the ceiling, escaped by the wall to its nest. In less than half an hour a great company of ants sallied out of their holes, climbed the wall, passed along ceiling, crept along the string into the pot, and began to eat again. This they continued to do until the treacle was all consumed, one swarm running up the string while another passed down. It seems indisputable that the one ant had in this instance conveyed news of the booty to his comrades, who would not otherwise have at once directed their steps in a body to the only accessible route.[†]

63. A similar example of knowledge gained by experience, in the case of the hive-bee, is related by Mr. Wailes.[‡] He observed that all the bees, on their first visit to the blossoms of a passion-flower (*Passiflora cærulea*) on the wall of his house, were for a considerable time puzzled by the numerous overwrapping rays of the nectary, and only after many trials, sometimes lasting two or three minutes, succeeded in finding the shortest way to the honey at the bottom of the calyx; but experience having taught them

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[*] Mémoires, vol. v., p. 709.

[†] Kirby and Spence, vol. ii., p. 422.

[‡] Entomological Magazine, vol. i., p. 525.

this knowledge, they afterwards constantly proceeded at once to the most direct mode of obtaining the honey; so that he could always distinguish bees that had been old visitors of the flowers from new ones, the latter being at a loss how to proceed, while the former flew at once to their object.

Fig. 16.—The Humble Bee.

64. A similar fact is related of the humble bees by Huber,* who, when their bodies are too large to enter the corolla of a flower, cut a hole at its base with their mandibles, through which they insert the proboscis to extract the honey. If these insects adopted this expedient from the first, and invariably followed it, the act might be ascribed to instinct; but as they have recourse to it only after having vainly tried to introduce their body in the usual way into the opening of the corolla, it can scarcely be denied that they are guided by intelligence in the attainment of their end. The marks of experience, memory, and comparison, are unequivocal. When they find their efforts to enter the first flower to which they address themselves fruitless, they do not repeat them upon other flowers of the same sort, but directly attack the base of the corolla. Huber witnessed such proceedings repeatedly in the case of bean-blossoms.

65. Insects give proofs without number of the possession of the faculty of memory, without which it would be impossible to turn to account the results of experience. Thus, for example, each bee, on returning from its excursions, never fails to recognise its own hive, even though that hive should be surrounded by various others in all respects similar to it.

66. This recognition of home is so much the more marked by traces of intelligence rather than by those of instinct, inasmuch as it depends not on any character merely connected with the

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* Philosophical Transactions, vol. vi., p. 222.

hive itself, whether external or internal, but from its relation to surrounding objects; just as we are guided to our own dwellings by the recollection of the particular features of the locality and neighbourhood. Nor is this faculty in the bee inferred from mere analogies; it has been established by direct experiment and observation. A hive being removed from a locality to which its inhabitants have become familiar, they are observed, upon the next day, before leaving for their usual labours, to fly around the hive in every direction, as if to observe the surrounding objects, and obtain a general acquaintance with their new neighbourhood.

67. The queen in like manner adopts the same precaution before she rises into the air, attended by her numerous admirers, for the purposes of fecundation.

68. This curious example of the memory of bees is beautifully noticed by Rogers, in his poem on that faculty.

> "Hark! the bee winds her small but mellow horn,
> Blithe to salute the sunny smile of morn.
> O'er thymy downs she bends her busy course,
> And many a stream allures her to its source.
> 'Tis noon, 'tis night. That eye so finely wrought,
> Beyond the search of sense, the soar of thought,
> Now vainly asks the scenes she left behind;
> Its orb so full, its vision so confined!
> Who guides the patient pilgrim to her cell?
> Who bids her soul with conscious triumph swell?
> With conscious truth retrace the mazy clue
> Of varied scents that charmed her as she flew?
> Hail, MEMORY, hail! thy universal reign
> Guards the least link of Being's glorious chain."

69. The poet, however, has fallen into an error, as often happens when poets derive their illustrations from physical science. The bee is not reconducted to its habitation by retracing the scents of the flowers it has visited; for, if it were, it is obvious that in returning it would necessarily follow the zig-zag and tortuous course from flower to flower which it had followed during the progress of its labours in collecting the sweets with which it is loaded; whereas, on the contrary, in its return, no matter what be the distance, it flies in a direct line to its hive.

70. Kirby mentions the following curious fact illustrating the memory of bees, which was communicated to him by Mr. William Stickney, of Ridgemont, Holderness.

About twenty years ago, a swarm from one of this gentleman's hives took possession of an opening beneath the tiles of his house, whence, after remaining a few hours, they were dislodged and hived. For many subsequent years, when the hives descended from this stock were about to swarm, a considerable party of scouts were observed for a few days before to be reconnoitring about the old hole under the tiles; and Mr. Stickney is persuaded that if suffered they would have established themselves there. He is certain that for eight years successively the descendants of the very stock that first took possession of the hole frequented it, as above stated, and *not* those of any other swarm; having constantly noticed them, and ascertained that they were bees from the original hive, by powdering them while about the tiles with yellow ochre, and watching their return. And even later there were still seen, every swarming season, about the tiles, bees which Mr. Stickney has no doubt were descendants from the original stock.

71. Among the instincts manifested by insects, there is none more remarkable or more admirable than that already mentioned, by which certain species provide a store of food for their young, which differs totally from their own aliment, and which they would themselves regard with disgust. The pompilides, a species resembling wasps, are endowed with this faculty. The insect in its adult state feeds, like the bee, upon floral juices. But its young, in the infant state of larva, is carnivorous. The provident mother, therefore, when she deposits her eggs, never fails to place beside each of them in the nest, in a place prepared to receive it, the carcase of a spider or of some caterpillar, which she has slain with her sting for that express purpose.

72. The carpenter bee presents another example of this remarkable instinct, boring with incredible labour in solid wood a habitation which, though altogether unsuitable to itself, is adapted with the most admirable fitness for its young. Among these, one of the most remarkable is the *Xylocopa violacea*, fig. 17, a large species,* a native of middle and southern Europe, distinguished by beautiful wings of a deep violet colour, and found commonly in gardens, where she makes her nest in the upright putrescent espaliers or vine-props, and occasionally in the garden-seats, doors, and window-shutters. In the beginning of spring, after repeated and careful surveys, she fixes upon a piece of wood suitable for her purpose, and with her strong mandibles


Fig. 17.—The Carpenter Bee.

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[*] Kirby, vol. i., p. 369.

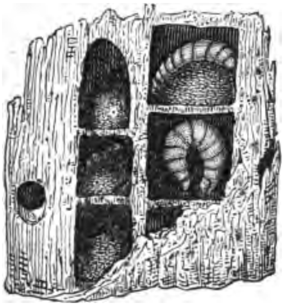

Fig. 18.—Nest of the Carpenter Bee.

begins the process of boring. First proceeding obliquely downwards, she soon points her course in a direction parallel with the sides of the wood, and at length, with unwearied exertion, forms a cylindrical hole or tunnel, not less than twelve or fifteen inches long and half an inch broad. Sometimes, where the diameter will admit of it, three or four of these pipes, nearly parallel with each other, are bored in the same piece.

Herculean as this task, which is the labour of several days, appears, it is but a small part of what our industrious bee cheerfully undertakes. As yet she has completed but the shell of the destined habitation of her offspring; each of which, to the number of ten or twelve, will require a separate and distinct apartment. How, you will ask, is she to form these? With what materials can she construct the floors and ceilings? Why, truly God "doth instruct her to discretion and doth teach her."

FIG. 23.—NESTS OF THE REPUBLICAN.

INSTINCT AND INTELLIGENCE.

CHAPTER III.

73. Habitations for the young provided more frequently than for the adults.—74. Birds' nests.—75. Nest of the baya.—76. Nest of the sylvia sutoria.—77. Anti-social instinct of carnivorous animals. —78. Their occasional association for predaceous excursions.—79. Assemblies of migratory animals.—80. Example of the migratory pigeons of America.—81. The beaver.—82. Their habitations.—83. Process of building their villages.—84. These acts all instinctive.—85. Low degree of intelligence of the beaver.—86. Method of catching the animal.—87. Social instinct of birds—The republican.—88. Habitation of wasps.—89. Formation of the colony—Birth of neuters. —90. Males and females.—91. Structure of the nest.—92. Form and structure of the comb.—93. Process of building the nest and constructing the combs.—94. Division of labour among the society.—95. Number and appropriation of the cells.—96. Doors of exit and entrance.—97. Avenue to the entrance.—98. Inferior animals not devoid of intelligence.—99. Examples of memory.—100. Memory of the elephant—Anecdote.—101. Memory of fishes.—102. Examples of reasoning in the dog.—103. Singular anecdote of a watch-dog.—104. Low degree of intelligence of rodents and ruminants proved by Cuvier's observations.—105. Intelligence of the pachydermata—the elephant—the horse—the pig—the pecari—the wild boar.—106. The quadrumana.—107. Cuvier's observations on the ourang-outang—marks of his great intelligence.

In excavating her tunnel, the carpenter bee has detached a large quantity of fibres, which lie on the ground like a heap of sawdust. This material supplies all her wants. Having deposited an egg at the bottom of the cylinder along with the requisite store of pollen and honey, she next, at the height of about three-quarters of an inch (which is the depth of each cell), constructs of particles of the sawdust, glued together, and also to the sides of the tunnel, what may be called an annular stage or scaffolding. When this is sufficiently hardened, its interior edge affords support for a second ring of the same materials, and thus the ceiling is gradually formed of these concentric circles, till there remains only a small orifice in its centre, which is also closed with a circular mass of agglutinated particles of sawdust. When this partition, which serves as the ceiling of the first cell and the flooring of the second, is finished, it is about the thickness of a crown piece, and exhibits the appearance of as many concentric circles as the animal has made pauses in her labour. One cell being finished, she proceeds to another, which she furnishes and completes in the same manner, and so on until she has divided her whole tunnel into ten or twelve apartments.

When the work here described is considered, it is evident that its execution must require a long period of hard labour. The several cells must be cut out, their floors agglutinated, and they must be each supplied with a store of honey and pollen, the collection and accumulation of which is a labour which must occupy a considerable interval of time; and as the eggs are deposited successively in the cells according as they are finished and furnished, it is evident that they must be at any given moment in very different states of progress, the young issuing from those first deposited many days before the latest break the shell. But since there are ten or twelve such chambers vertically superposed, and since the lowest are the first laid, the new-born larva would either be condemned to be imprisoned in its cell until the births of all those above it should take place, or, in escaping to the exterior, it would have to pass through the chambers of all the others not yet developed, and would thus damage or destroy them. The beneficent Creator of the insect has, however, endowed it with an instinct which supplies the place of the foresight necessary to provide against such a catastrophe. With admirable forethought she constructs, besides the door already mentioned leading from cell to cell, another orifice in the lowest cell, which serves as a sort of postern, through which the insects produced from the earliest eggs emerge into day. In fact, all the young bees, even the uppermost, make their exit by this road; for each grub, when about to pass into the state of pupa, places itself in its cell with its head downwards, and is thus necessitated, when arriving at the perfect state, to pass through the floor in that direction.*

73. It is especially in the first moment of their lives that animals in general are feeble, tender, and helpless, and have need of shelter from atmospheric vicissitudes, and protection from the attacks of their enemies; and we find, accordingly, that it is precisely these directions which have been given to the most irresistible instincts with which Almighty Goodness has endowed their parents. The number of species which in mature age build habitations for their own use, is insignificant compared with those which construct, with a labour which seems guided by the most touching tenderness and forethought, habitations for their young.

74. This habit is especially observable with birds. It is impossible to regard with sentiments other than those of the most profound interest the perseverance with which these creatures bring—straw by straw, and hair by hair—the materials destined for the formation of their nests, and the art with which they arrange them. The form, structure, and locality of these habitations is always the same for the same species, but different for different species, and are ever admirably adapted to the circumstances in which the young family are destined to live. Sometimes these cradles are constructed in the earth, and in a rude manner; sometimes they are cemented to the side of a rock, or to the wall of a building, but more commonly they are placed in the branches of trees, a hemispherical form being given to them (fig. 19.) They resemble, in form and structure, a little basket, rounded at the bottom and hollowed out at the top, the sides of which are formed of blades of grass, flexible straws and twigs, and hairs taken from the wool of animals, the inside being lined with moss or down.

Fig. 20.—Nest of the Baya.

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* Reaum. vi. 39—52; Mon. Ap. Angl. i. 189; Apis. * * a. 2. β.

75. Sometimes, however, a much more complicated and artificial structure is produced. The nest of the baya, a little bird of India, resembling the bullfinch, (fig. 20,) has the form of a flask, and is suspended from some branch which is so flexible that neither serpents, monkeys, nor squirrels can approach it. But still more effectually to secure the safety of their young, the mother places the door of the nest at the bottom, where it can only be reached by flying. This habitation would be liable to fall to pieces if it were formed of straws or filaments laid horizontally; it is, therefore, constructed with admirable skill of blades or filaments arranged longitudinally. Internally it is divided into several chambers, the principal of which is occupied by the mother sitting on her eggs; in another the father of the family is accommodated, who is assiduous in his attentions to his companion, and while she fulfils with exemplary tenderness her maternal duties he amuses her with his song.

76. Another oriental bird, called the sylvia sutoria, or sewing wood-bird, builds a nest equally curious. This little creature, collecting cotton from the cotton-tree, spins it with its bill and claws into threads, with which it sews leaves round its nest, so as to conceal its young from their enemies (fig. 21).


Fig. 21.—Nest of the Sylvia Sutoria.

77. Different species of animals are governed by social instincts which vary, but are always conducive either to the preservation or the well-being of the individual, or to the continuance of the race. When the food by which they are nourished is not so abundant as to support any considerable numbers in the same locality—which is generally the case with the larger species of carnivorous animals—they are endowed with an antisocial instinct, and not only lead a solitary life, but in many cases will not suffer any animal of their own species to remain in their neighbourhood.

78. Occasionally, however, the operation of this instinct is suspended. This takes place either when a scarcity of subsistence forces them to seek for food in places where they would be liable to attacks, against which their individual force would be insufficient for defence, or where some large flocks of animals of the sort on which they prey happen to come into their neighbourhood. In such cases they assemble by common consent in considerable numbers, and attack their prey in a body. Thus

we see in the winter season bands of wolves, impelled by hunger, descend from the hills or forests and ravage the stock of the farmer,—an enterprise on which they never venture when other food can be obtained at less risk. In such cases, however, when the immediate object of their enterprise has been accomplished, their antisocial instinct revives, and they disperse, often quarrelling among themselves.

79. Various species which do not habitually live in society, nevertheless assemble in vast numbers, when at certain seasons they make long journeys. This is the case generally with migratory animals. The social instinct is, however, only temporary, since, when the journey is completed, and they arrive at their destination, they disperse.

80. The migratory pigeons of North America present a remarkable example of this instinct, of temporary and periodical sociability. These birds, when stationary, are dispersed in vast numbers over the country, but when about to migrate, they assemble in inconceivable numbers, and perform their journey together, flying in a close and dense column nearly a mile in width, and six or eight miles in length. Wilson, the well-known American ornithologist, saw a flock of these birds pass over him in the state of Indiana, the number of which he estimated at two millions. The celebrated Audubon related that one day in autumn, having left his house at Henderson, on the banks of the Ohio, he was crossing an inclosed tract near Horsdensburgh, when he saw a flight of these pigeons, more than commonly numerous, directing their course from the north-west towards the south-east. As he approached Louisville, the flock became more and more numerous; he described its density and extent to be such, that the light of the sun at noon was intercepted, as it would have been by an eclipse, and that the dung fell in a thick shower like flakes of snow. Upon his arrival at Louisville, at sunset, having travelled fifty-five miles, the pigeons were still passing in dense files. In fine, this prodigious column continued to pass for three entire days, the whole population having risen and resorted to fire-arms to destroy them.

The usual habitations of these birds are the extensive woods which overspread that vast continent. A single flock will often occupy one entire forest; and when they remain there some time, their dung is deposited on the ground in a stratum several inches thick. The trees are stript throughout an extent of many thousand acres, and sometimes completely killed, so that the traces of their visit are not effaced for many years.

81. Of all mammifers, the Canadian beaver is the most remarkable for sociability, industry, and foresight. During the summer

it lives alone in burrows, which it excavates on the borders of lakes and rivers; but on the approach of winter, the animals quit these retreats, and assemble together for the purpose of constructing a common habitation for the winter season. It is in the most solitary places that they display their architectural instinct.

82. Two or three hundred having concerted together, select a lake or river too deep to be frozen to the bottom, for the establishment of their dwellings. They generally prefer a running stream to stagnant water, because of the advantage it affords them as a means of transport for the materials of their habitation. To keep the water at the desired depth, they commence by constructing a dam or weir in a curved form, the convexity being directed against the stream. This is constructed with twigs and branches, curiously interlaced, so as to form a sort of basket-work, the interstices being filled with gravel and mud, and the external surface plastered with a thick and solid coating of the same. This embankment, the width of which, at its base, is commonly from twelve to fourteen feet, lasts, when once constructed, from year to year, the same troop of beavers always returning to pass the winter under its shelter. Their labours after the first season are limited to keeping it in repair; they strengthen it from time to time by new works, and restore whatever may be worn away by the action of the weather. It is rendered more permanent by a vigorous vegetation, which soon clothes its surface.

83. Wherever stagnant water has been selected, this preliminary labour becomes unnecessary, and the animals proceed at once to build their village. But, as has been already observed, they are subject in that case to an equivalent amount of labour in the transport of the materials.

When this preliminary work has been completed, they resolve themselves into a certain number of families, and if the locality is a new one, each family sets about the construction of its huts; but if they return to the village they inhabited a former year, their labour is limited to the general repair and cleansing of the village.

The cabins composing it are erected against the dam, or upon the edge of the water, and generally have an oval form. Their internal diameter is six or seven feet, and their walls, like the dam, constructed of twigs and branches, are plastered on both sides with a thick coating of mud. The cabin, of which the foundation is below the surface of the water, consists of a basement and an upper storey, the latter being the habitation of the animals, and the former serving as storeroom for provisions.

The entrance to the cabin is in the basement story, and below the level of the water.

It has been supposed that the animal uses its tail as a trowel in building these habitations. It appears, however, that this is an error, and that they use only their teeth and the paws of their fore-feet. They use their incisive teeth to cut the branches, and when necessary the trunks of trees; and it is with their mouth and their fore-feet that they drag these materials to the place where they intend to erect their habitation. When they have the advantage of running water, they take care to cut their wood at a point on the banks of the stream above the place where they are about to build. They then push the materials into the water, following and guiding them as they float down the stream, and landing them, in fine, at the point selected for their village. It is also with their feet that they excavate the foundations of their dwellings. These labours are executed with great rapidity and chiefly during the night.

Fig. 22.—The Beaver.

84. The beaver, being a mammifer of the order of rodents, is one of the classes to which Cuvier assigns, as has been already stated, the lowest degree of intelligence. If the various acts here related were assigned to intelligence, they would evince a high degree of that faculty. Cuvier, however, demonstrated conclusively that they were acts altogether instinctive. He took several young beavers from their dams, and reared them altogether apart from their species, so that they had no means of acquiring any knowledge of the habits and manners of their kind. These animals, brought up in cages, isolated and solitary, where they had no natural necessity for building huts, nevertheless, pushed by the blind and mechanical force of instinct, availed themselves of materials, supplied to them for the purpose, to build huts.

85. In the low estimate of intelligence assigned by Cuvier to the beaver, other naturalists concur. "All agree," says Buffon, "that this animal, far from having an intelligence superior to others, as would necessarily be the case if his architectural skill were admitted to be the result of such a faculty, appears, on the contrary, to be below most others in its individual qualities. It is an animal, gentle, tranquil, familiar; of plaintive habits, without violent passions or strong appetites. When confined it is impatient to recover its liberty, gnawing from time to time the bars of its cage, but doing so without apparent rage or precipitation, and with the sole purpose of making an opening by which it may get out. It is indifferent; shows no disposition to attachment, and seeks neither to injure nor to please those around it. It seems made for neither obedience nor command, nor even to have commerce with its kind. The spirit of industry which it displays when assembled in troops, deserts it when solitary. It is deficient in cunning, without even enough of distrust to avoid the most obvious snares spread for it; and, far from attacking other animals, it has not the courage or skill to defend itself."

86. The pursuit of the beaver has been prosecuted to such an extent in Canada, that the animal has been nearly exterminated there, and more recently the trappers have been obliged to extend their excursions in search of them to the sources of the Arkansas, in the Rocky Mountains. The snare or trap used for catching the animal is similar to that used for foxes and polecats. The trappers, who make their excursions in caravans for mutual protection against the attacks of the Indians, acquire such skill, that they discern at a glance the track of the animal, and can even tell the number which occupy the hut. They then set their traps at a few inches below the surface of the water, and connect them by chains to the trunk of a tree, or to a stake planted strongly in the bank. The bait consists of a young twig of willow, stripped of its bark, the top rising to five or six inches above the surface of the water. The twig has been previously steeped in a sort of decoction made from the buds of poplar, mint, camphor, and sugar. The beaver, being gifted with a fine sense of smell, is attracted by the odour, and in touching the twig he disengages the detent of the trap and is caught.

87. The social instinct is not so common among birds as with mammifers, nevertheless some remarkable examples of it are found, among which may be mentioned a species of sparrow called the *republican*, which lives in numerous flocks in the neighbourhood of the Cape of Good Hope. These birds construct a roof (fig. 23), under which the whole colony build their nests.

88. But it is among insects we must look for the most striking manifestations of the architectural instinct.

The wasp (fig. 24.) affords an example of this, scarcely less interesting than the well-known economy of the bee. These little animals, though ferocious and cruel towards their fellow insects, are civilised and polished in their intercourse with each other, and compose a community whose architectural labours will not suffer by comparison even with those of the peaceful inhabitants of the hive. Like the latter, their efforts are directed to the erection of a structure for their beloved progeny, towards which they manifest the greatest tenderness and affection. They construct combs consisting of hexagonal cells for their reception; but the substance they use for this purpose is altogether different from wax, and their dwelling is laid out upon a plan in many respects different from that of the bee.

Fig. 24.—The Wasp.

89. Their community consists of males, females, and neuters. At the commencement of spring a pregnant female, which has survived the winter, commences the foundation of a colony destined before the autumn to become a population of some twenty or thirty thousand. The first offspring of this fruitful mother are the neuters, who immediately apply themselves to the task of constructing cells, and collecting food for the numerous members of the family who succeed them; and it is, while engaged in this labour, that they are most disposed to avenge themselves upon all who attempt to molest or interrupt them.

90. It is not till towards the autumn that the males and females are brought forth. The males as well as the neuter soon die, and the females surviving, seek some place of refuge in which to pass the winter, being previously impregnated.

91. The nest of the common wasp, generally built under ground, is of an oval form, from sixteen to eighteen inches high, and from twelve to thirteen in diameter.

Another species builds a nest of nearly the same form, but suspends it from the branches of trees; the size of these suspended nests varying from two inches to a foot in diameter. A section of the underground nest of a common wasp is shown in fig. 25.

It is a singular fact that the material of which the wasp builds its habitation is paper, an article fabricated by this insect ages before the method of making it was discovered by man.

With their strong mandibles they cut and tear from any pieces of old wood to which they can find access, a quantity of the woody fibre, which they collect into a heap and moisten with viscid liquid secreted in their mouths. They knead this with their jaws until they form it into a mass of pulp similar precisely to that which the paper-maker produces from the vegetable fibre of linen or cotton rags. With this pulp, they fly off to their nests, where, by walking backwards and forwards, they spread it out into leaves of the necessary thinness by means of their jaws, tongue, and legs. This operation is repeated many times, until at length as much of the paper is produced as is sufficient to roof in the nest. The thinness of this wasp-made paper is about the same as that of the book now in the hands of the reader.

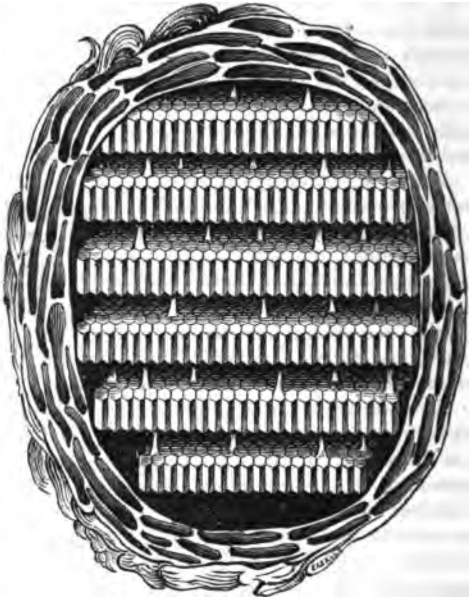

Fig. 25.—Underground Wasp's nest.

The coating of the nest consists of fifteen or sixteen leaves of this paper placed one outside the other, with small spaces between them as shown in the figure, so that if rain should chance to penetrate one or two of them, its progress may be arrested by the inner ones.

92. The interior of the nest consists of from twelve to fifteen horizontal layers of comb placed one over the other so as to form

as many distinct and parallel storeys. And here we may observe in passing, the difference between the architectural system of the wasp and that of the bee. The latter builds its cells in vertical strata ranged side by side, the mouths opening horizontally so that the insects in passing between stratum and stratum must creep up the intervening vertical corridors; while the wasp, on the other hand, prefers horizontal corridors, so that in passing between stratum and stratum it creeps over one and under the other. In short, the positions given to the ranges of comb by the bee, in contradistinction to that adopted by the wasp, will be understood by supposing the sides of the wasp's habitation to represent the top and bottom of that of the bee.

Each comb of the wasp is composed, as shown in the figure, of a numerous assemblage of hexagonal cells made of the same paper as that already described, each cell being distinct, with double partition-walls. These cells, unlike those of the hive bee, are arranged only in a single row, the open end of each cell being turned downwards and the upper end being closed by a slightly convex lid, and not by a pyramidal cover like those of the honeycomb. The upper surface of each stratum of comb is therefore a continuous floor formed like an hexagonal mosaic, the surface being nearly but not perfectly smooth, since each hexagonal piece is curved slightly upwards.

The open mouths of the cells being presented downwards, the nurses as they creep along the roof of each stratum can easily feed the young grubs which occupy the cells of the stratum immediately above. The space left between one stratum and another is about half an inch.

Each stratum of comb is attached at the sides of the walls of the nest, but the tenacity of the paper of which the comb is composed would not be sufficient to sustain the weight of the stratum when the cells are all filled with grubs. The little architects, therefore, as though they had foreseen this, take care to connect at regulated intervals each stratum with that below it by strong cylindrical columns or pillars. Each of these, like the columns used in architecture, has a base and a capital, to which greater dimensions are given than those of the connecting shaft. These columns are composed of paper similar to that used for other parts of the nest, but of a more compact and stronger texture. The middle strata are connected by a colonnade of from forty to fifty of these pillars; the number being less as the dimensions of the strata decrease in going upwards or downwards.

93. The process of building this structure is as follows. The dome is first completed, as already described; by laying fifteen or

sixteen little sheets of paper one under the other, with intervening spaces at each part of it. Before the walls are further continued, the first or uppermost stratum of comb is then fabricated and attached to the sides by paper cement, and to the roof by a colonnade of pillars. The empty cells of this stratum being ready, the female big with eggs, deposits an egg in each, which is retained there by being agglutinated to the roof and sides of the cell: meanwhile, the workers continue their architectural labours, first carrying downwards the paper walls as already described, and next constructing the second stratum of comb and connecting it with the first by a colonnade.

94. It must be observed that in the society there is a well-organised division of labour. One part of it is employed exclusively in building, another in collecting food for the young, and in tending and nursing them, and, in fine, the female in depositing eggs in the cells. Since, therefore, a comparatively small proportion of the colony is engaged in building, the progress of the structure is necessarily slow, its entire completion being the work of several months; yet, though the result of such severe labour, it merely serves during the winter as the abode of a few benumbed females, and is entirely abandoned on the approach of the spring, wasps never using the same nest for more than a single season.*

95. The cells, which in a populous nest are not fewer than 16000, are of different sizes, corresponding to that of the three orders of individuals which compose the community; the largest for the grubs of females, the smallest for those of workers. The last always occupy an entire comb, while the cells of the males and females are often intermixed.

96. Besides openings which are left between the walls of the combs to admit of access from one to the other, there are at the bottom of each nest two holes, by one of which the wasps uniformly enter, and through the other issue from the nest, and thus avoid all confusion or interruption of their common labours.

97. As the nest is often a foot and a half under ground, it is requisite that a covered way should lead to its entrance. This is excavated by the wasps, who are excellent miners, and is often very long and tortuous, forming a beaten road to the subterraneous dwelling, well known to the inhabitants, though its entrance is concealed from incurious eyes. The cavity itself, which contains the nest, is either the abandoned habitation of moles or field mice, or a cavern purposely dug out by the wasps, which exert themselves with such industry as to accomplish the arduous undertaking in a few days.†

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* Reaum. vi. 6.

† Kirby, vol. i. p. 426.

98. While it is incontestable that instinct is the predominant spring of action with the inferior species, it is nevertheless impossible to deny many animals the possession of a certain degree of intelligence. Many are evidently endowed, not only with memory, but even with judgment, and a certain degree of the reasoning faculty.

99. That many species possess the faculty of memory in a high degree of development is evident. Domesticated animals in general know and remember their homes and their owners. A horse, even after having made a single excursion from his stable, will recognise the road to it on his return, and it is even affirmed that upon returning after several years' absence to a locality which he has inhabited for a sufficient time to become familiar with it, he will again recognise it, and left to himself will find his way into the stable he formerly occupied, and resume the possession of his former stall. The dog, the elephant, and other domesticated animals, recognise, even after longer intervals, those who have treated them well or ill, and manifest accordingly their gratitude or their vengeance.

100. It happened not long since that an elephant in one of the collections publicly exhibited in this country, extending his trunk between the bars of his stall, suddenly struck down with it an individual among a crowd of spectators, obviously selected by the animal for the infliction of the blow. A circumstance so singular excited inquiry, more especially as it was seen that the person attacked had not in any way at the time offended or molested the animal. It was ascertained, however, upon inquiry, that some weeks previously the same individual had visited the menagerie, and had pricked the extremity of the trunk of the creature with some sharp instrument, taking care in doing so to be beyond its reach.

101. Even fishes do not appear to be altogether destitute of memory, since eels approach upon the call of their keeper. Serpents in menageries also manifest the same faculty.

102. The actions by which animals show the exercise of a certain degree of reasoning are scarcely less numerous. Thus, the dog, which is kept in a cage, will gnaw the bars if they are of wood, but will quietly resign himself to his captivity if they are of iron, because he understands that since he can make an impression on the bars in the first case by gnawing them, he may by continued efforts cut them through and effect his liberation; but finding the first efforts in the other case unavailing, he infers that their continuance could never accomplish his object.

When a dog sees his master put on his hat, the animal infers at once that he is going out, and jumping upon him loads him with caresses to induce his master to take him as his companion. In this case there is reasoning, comparison, judgment, and a certain degree of generalisation. The dog *generalises* the act of putting on the hat, and *infers* its consequences, he *remembers* the act done on former occasions, and that it was followed by a walk abroad on the part of the master, and he *concludes* that what took place before will under like circumstances occur again.

103. A watch-dog, which was habitually chained to his box, found that his collar was large enough to allow him to withdraw his head from it at will. Reflecting, however, that if he practised this manœuvre when exposed to the observation of his master or keeper, the repetition of the act would be necessarily prevented by the tightening of the collar, he refrained from practising it by day, but availing himself of the expedient by night, roamed about the adjacent fields which were stocked with sheep and lambs, some of which, on these occasions, he would wound or kill. Bearing on his mouth the marks of his misdeeds, he would go to a neighbouring stream to wash off the blood, having done which he would return to his box before daybreak, and, slipping his head into the collar, lie down in his bed as though he had been there during the night.

104. In the series of observations and experiments by which F. Cuvier demonstrated the gradually increasing share of intelligence given to mammifers, proceeding from the lowest to the highest species, he showed from observations made on the habits and manners of marmots, beavers, squirrels, hares, &c., that rodents in general do not possess even that common degree of intelligence which would enable them in all cases to recognise their master or to know each other. The limited intelligence of the ruminants was shown in the case of a bison in the menagerie of the Garden of Plants, which having learned to recognise its keeper, ceased to know him when he changed his dress, and attacked him as it would have attacked a stranger. The keeper having resumed his original costume, was instantly recognised by the animal.

Two Barbary rams, which occupied the same stall, having been shorn, ceased to recognise each other, and immediately engaged in battle.

105. The manners of the elephant and horse are in obvious accordance with the rank assigned to them by Cuvier in the order of intelligence. But the pig species might seem at the first more doubtful. Nevertheless, Cuvier found that it was very little inferior to the elephant in sagacity. He found that the pecari, or South American hog, was as docile and familiar as the best trained dog. The wild boar is easily tamed,

recognises and obeys his keeper, and is capable of learning certain exercises.

106. The increasing degree of intelligence ascending from the Carnivora to the Quadrumana was clearly established by the observations of Cuvier, who found that in accordance with his system, the ourang-outang, of all mammifers, manifested the highest degree of intelligence.

107. A young ourang-outang, of the age of fifteen or sixteen months, was an especial object of observation and experiment. He showed the greatest desire for society, manifesting the strongest attachment for those who had charge of him. He loved to be caressed by them, and used not only to embrace, but even to kiss them. He pouted like a child when not allowed to have his way, and testified his vexation by cries, rolling himself on the ground, and striking his head upon it, so as to excite compassion by hurting himself.

This animal used to amuse itself by climbing up the trees in the Garden of Plants, and perching on their branches. It happened one day, that the keeper attempted to climb the tree to catch it. The ourang-outang immediately shook the tree with all its force, so as to deter the keeper from mounting it. The keeper then retired, and after an interval returned, approaching the tree, when the ourang-outang again set itself to shake the branches. "In whatever manner," says Cuvier, "this conduct may be viewed, it will be impossible not to see in it a combination of ideas, and to recognise in the animal capable of it the faculty of generalisation."

In fact, the ourang-outang in this case evidently reasoned by analogy from himself to others. He had already experienced the alarm excited in his own mind by the violent agitation of the bodies on which he was supported. He argued, therefore, from the fear which he felt himself to the fear which others would suffer in like circumstances. In other words, as Cuvier justly observes, he erected a general rule upon the basis of a particular circumstance.

This animal being one day shut up alone in a room, it availed itself of a chair which happened to be placed at the door, upon which it mounted to reach the latch. To prevent this manœuvre the keeper removed the chair; but the animal, when he had departed, seized another chair which was at a distance from the door, and placing it under the latch, mounted upon it in like manner.

In this case we find all the indications of memory, judgment, generalisation, and reasoning. The case is totally different from those so frequently witnessed in the case of animals trained for exhibition. The animal had never been taught to mount upon a chair to reach the latch of the door, nor had he ever seen any one do so. It must therefore have been by his own experience alone that he learned to perform the act. By observing the actions of his keepers, he learned that chairs could be removed from one place to another. Generalising this, he inferred that he could remove a chair to the door. He learned also by his own experience, that by mounting on chairs and tables, he could reach objects which were unattainable from the floor, and, generalising this experience, inferred that he could by the same expedient reach the latch.*

It is impossible in cases like these to admit instinct as an explanation of the phenomenon. The circumstances under which such acts are performed, and the consequences which attend them, are incompatible with all the conditions usually attached to the faculty of instinct.

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* Milne Edwards's Zoology, p. 256.

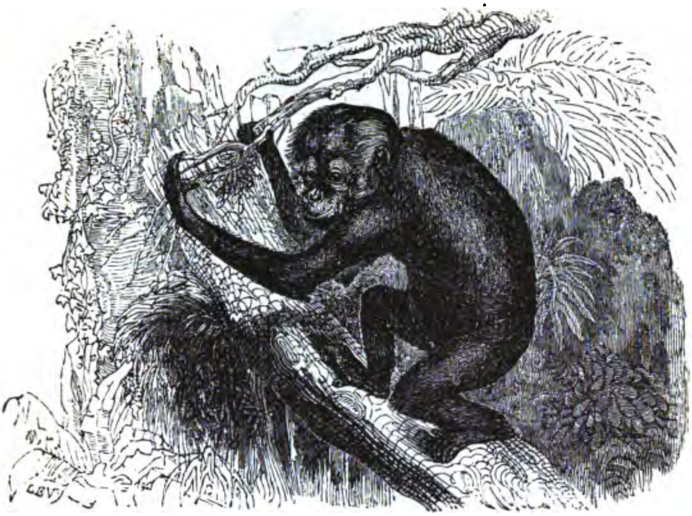

FIG. 27.—OURANG-OUTANG.

INSTINCT AND INTELLIGENCE.

CHAPTER IV.

108. Anecdotes of the Ourang-Outang.—109. Analogy of the skeleton of the Ourang-Outang to that of Man.—110. Of the brain to the human brain.—111. Intelligence of the Wolf.—112. Anecdote of the Hawk, the Cat, the Eagle.—113. Of the Dog.—114. Of the Bear. —115. Intelligence of animals decreases with age.—116. Man distinguished from other animals by the degree of intelligence.—117. Lower animals are not endowed with reflection.—118. Inferior animals have methods of intercommunication as a substitute for language.—119. Examples in the cases of marmots, flamingoes, and swallows.—120. Intercommunication of ants.—121. Example in their mutual wars.—122. Acts which cannot be explained either by instinct or intelligence.—123. Carrier-pigeons.—124. Domesticity and tameness.

108. THE ourang-outang has been a subject of observation with all naturalists who have devoted their labours to the investigation of the habits of animals.

Buffon records circumstances respecting this animal that places him in close relation with man. Thus he has seen him present his hand to visitors to conduct them to the door, walk gravely with them as a friend or companion would, sit at table and spread his napkin in a proper manner, and wipe his lips with it, use a

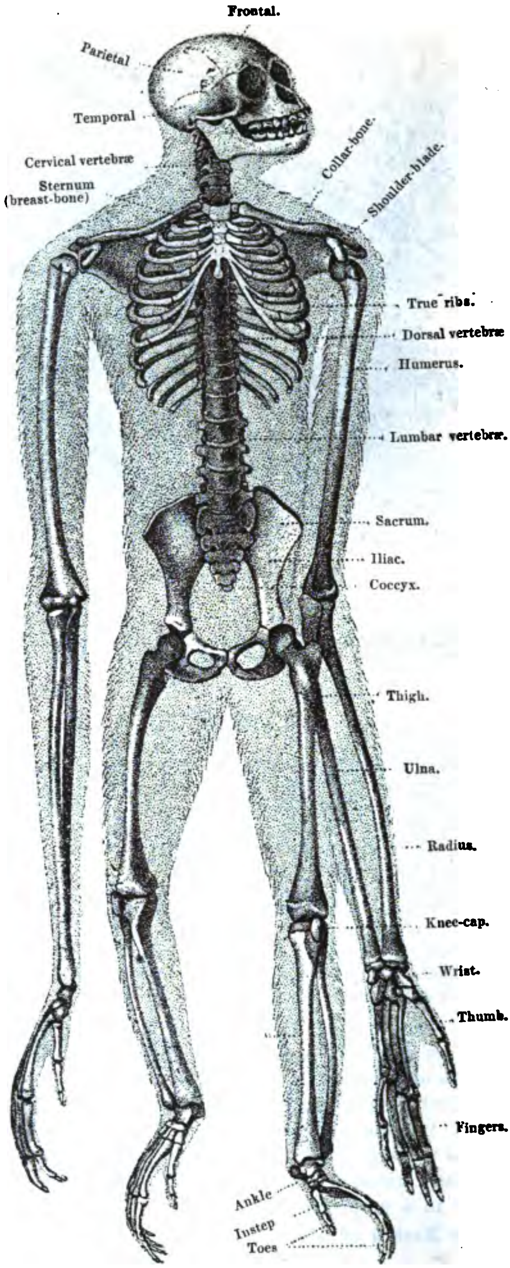

Fig. 28.—Skeleton of Ourang-Outang.

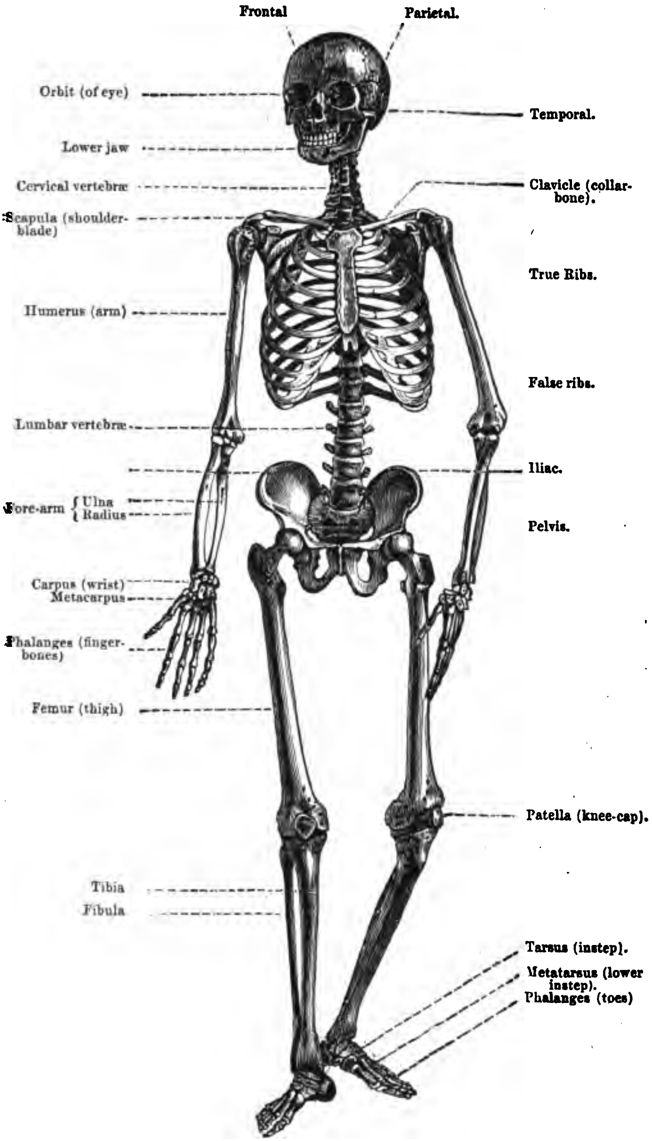

Fig. 29.—Human Skeleton.

spoon and fork to convey food to his mouth, pour wine into a glass and drink it, take wine with another at the table when so invited, clinking the glass according to the French custom; he would go and fetch a cup and saucer, put them on the table, put sugar in the cup, pour tea into it, and leave it to cool before drinking it, and all this without any prompting on the part of the master. He was circumspect in approaching persons, to avoid the appearance of rudeness, and used to present himself like a child desirous of receiving caresses.

M. Flourens found the same marks of intelligence in an ourang-outang in the Garden of Plants. This animal was gentle and sensible to caresses, especially from children, with whom he was always delighted to play.

He could lock and unlock the door of his room, and would look for the key of it. He showed none of the petulance and impatience common to apes. His air was serious, his gait grave, and his movements measured.

It appeared one day that an illustrious old savant accompanied M. Flourens to visit the animal. The figure and costume of this gentleman were singular. His body stooped, his gait was feeble, and movement slow. These peculiarities evidently attracted the notice of the animal. While he acquiesced with all that was desired of him, his eye was never withdrawn from his strange visitor. When they were about to retire, the animal, approaching the old gentleman, took with a certain expression of archness the cane from his hand, and affecting to support himself upon it, bent his back and hobbled round the room, imitating the gait and gestures of the stranger, after which, with the greatest gentleness, he returned to him the walking-cane.

"We quitted the ourang-outang," says M. Flourens, "convinced that philosophers are not the only observers in the world."

109. The close analogy of the structure of the ourang-outang to that of man will render this high degree of intelligence less surprising. This analogy is even more apparent in the skeleton than in the mere external form, as will be seen by comparing the fig. 28, which is that of the ourang-outang, with fig. 29, which is that of man.

110. An analogy not less striking is apparent in the brain of the animal compared with the human brain. In fig. 30 a side view of the human brain is presented, and in fig. 31 a similar view of the brain of the ourang-outang.

111. Leroy had already observed in the wolf, like signs of generalisation. When that animal appears, he is pursued, and the assemblage and tumult announce to him at once how much he is feared, and all that he has himself to dread. Hence, when-

ever the scent of man strikes his sense, it awakens in him the idea of danger. While this fearful accessory attends it, the

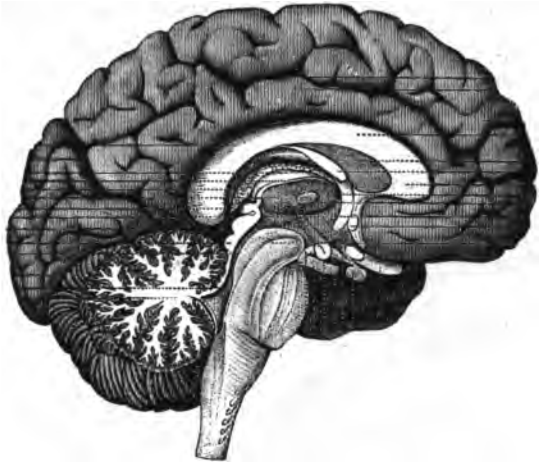

Fig. 30.—Human Brain.

Fig. 31.*—Brain of the Ourang-Outang.

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* This figure is slightly incorrect. The brain of the ourang does not quite overlay the cerebellum.

most seductive prey will not attract him; and even when the cause of danger is not present, the desired object is long regarded with suspicion. The wolf therefore, observes Leroy, must necessarily have an abstract idea of the danger, since he cannot be supposed to have a knowledge of the snares which are spread for him on any particular occasion.

112. The following curious anecdote of the habits of hawks and falcons is related by M. Dureau de la Malle.*

These birds, when they return from the pursuit of their prey at the season when their younglings have become sufficiently fledged to rise on the wing, bring back in their talons some object, such as a mouse or sparrow, which they have killed, for the purpose of giving a lesson to their young in the art of capturing their prey. These birds are observed to have peculiar calls, which their young understand, and which are always repeated for the same purpose. M. de la Malle, who had a lodging in the Louvre, observed one day a male and female falcon thus returning and bringing with them a dead sparrow in their talons. They soared in the air over their nest, calling their younglings with the cry intended to summon them to rise on the wing. When the young birds thus rose, the old ones,

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* Mémoire sur le dévellopement des facultés intellectuelles des Animaux.

soaring vertically over them, let fall the sparrow, upon which the younglings pounced. In the first attempts, the latter invariably failed in seizing the sparrow, not being yet sufficiently adroit. The old birds would then descend, and, seizing the prey, rise with it into the air once more, and let it fall again upon the young; nor would they allow the latter to devour it until they succeeded in catching it as it fell.

These lessons were progressive. The prey first let fall on their younglings was dead. When they had acquired sufficient skill to seize this in falling through the air, the old parents brought living birds, first more or less disabled, and afterwards uninjured, upon which they exercised their young in the same manner; and this was continued until the young birds were fully able to pursue and seize their prey without further practice or instruction.

Every one has seen the cat give to her kittens similar progressive lessons.

She commences by biting a mouse so as to stun, or slightly disable, without killing it. She then liberates this mouse before her kittens, and encourages them to pursue it, the matron cat standing by, a vigilant observer of the scene. If the mouse shows any sign of escaping, she immediately pounces upon it, and disables it so effectually, that her kittens soon finish it.

According to Daubenton, the eagle carries its eaglet aloft upon its wings, and letting it go in mid air, tries its powers of flight. If its strength fails, the mother is sure to be at hand to support it.

113. Among the acts of animals which are obvious results of intelligence and not of instinct, the following may serve as instructive and interesting examples:—

Plutarch relates, that a dog desiring to drink the oil contained in a pitcher with a narrow mouth, the surface of the liquid being so low as to be out of the reach of his mouth, threw pebbles into it, which sinking in the oil, caused its surface to rise so high that the dog could lap it up. According to Plutarch, the dog must in this case have reasoned thus: the pebbles being heavier than the oil will sink to the bottom; they will displace part of the oil, and will displace more and more the more of them that are thrown in; therefore by throwing in a sufficient number, the surface of the oil must necessarily rise to the dog's mouth.

114. M. Flourens relates the following anecdote of bears in the Garden of Plants:—

It happened that these animals multiplied until there were more of them than it was desired to keep, and it was resolved to get rid of two. It was proposed to poison them with prussic acid. For this purpose some drops of that liquid were poured upon little cakes, which being offered to the bears in the usual way, the animals stood up on their hind legs, and opened their mouths to catch them. The moment they received them, however, they spat them out, and retired to a remote corner of their den, as though they were frightened. After a short interval, however, they returned to the cakes, and pushed them with their paws into the water-trough left to supply them with drink, and there they carefully washed them by agitating them to and fro in the water. After this they smelled them, and again washed them, and continued this process until the poison was washed off, when they ate the cakes with impunity. All the poisoned cakes given to them were thus treated, while all the cakes not poisoned were devoured immediately.

The animals which had shown these singular marks of intelligence were spared the fate to which they had previously been condemned.

115. One of the most remarkable circumstances attending the faculty of intelligence, observed not only in the ourang-outang, but in all species of apes, is that its greatest development is manifested when the animal is young, and that instead of improving, it decreases rapidly with age. The ourang-outang when young excites surprise by his sagacity, cunning, and address. Having attained the adult state, he is a gross, brutal, and intractable animal.* In this, as well as in all other species of apes, the decrease of intelligence is commensurate with the increase of growth and strength. The intelligence of the animal, therefore, such as it is, is not like that of man, perfectable.

116. It is established, therefore, by the observations and researches of naturalists, that intelligence is a faculty common to man and to inferior animals. According to some, man is distinguished from other animals only by the degree in which he is endowed with this faculty; and the difference of degree is so immense, that, before accurate observations had proved the contrary, the faculty of intelligence was deemed the exclusive gift of the human race. Others contend that the intelligence of man differs from that of animals not in *degree* only, but in *kind;* that, in short, what is called intelligence in animals, is a faculty essentially different from what is called intelligence in man, and ought to have been called by a different name.

The intelligence of animals is limited and stationary. It is unimproveable and incommunicable. The intelligence of man, on the contrary, is susceptible of improvement without limit, and

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* Flourens, "De l'Instinct et de l'Intelligence des Animaux," p. 35.

may be imparted from individual to individual. It radiates like light. Its power of growth and improvement is indefinite.

As we observed before, much of the obscurity and confusion which has attended all discussion respecting the intelligence of animals, arose from the omission of a sufficiently clear line of demarcation between instinct, properly so called, and intelligence.

The great purposes of instinct are the preservation of the individual and the continuance of the species. To plants, which live and die without change of place, the Creator has given strong and elastic tissues to ensure the preservation of the individual, and myriads of germs are put in immediate juxta-position with the organs destined to fecundate them, to ensure the continuance of the species.

To animals, which are endowed with powers of locomotion, and which are thereby exposed to numerous vicissitudes, God has given instinct to preserve the individual, to reproduce the species, and to perpetuate His work, thus rendering them unconscious agents in fulfilling His almighty command to "increase and multiply."

Instinct is then a gift emanating direct from divine goodness, and being a gift, and not a faculty, is inexplicable. It is a power inseparable from animal life. Its dictates are as imperious as those of gravitation or magnetism. It can neither be modified nor evaded. The bee constructs her comb in one manner and on one plan, from which no bee, old or young, ever departs. The bird builds its nest after a fashion as uniform, and by a law as rigorous, as that by which the lilies of the field put forth their blossoms.

Nor is man himself more emancipated from the sway of instinct. His first act on coming into the world is the instinctive seizure of the maternal nipple. Fear is the instinct of self-preservation; love that of the continuance of the species.

Intelligence on the one hand is the power of comprehending the consequences of acts, and of giving to them a direction determined by the will of the agent.

Reason is the most exalted form of intelligence, so exalted that some contend that it ought to be considered as a distinct faculty. It is by reason that man knows himself, judges himself, and conducts himself.

Animals are variously gifted with intelligence, for they are endowed with perception, memory, and consciousness. They are susceptible of passions and affections, not only physical, but moral. All the human passions, anger, hatred, jealousy and revenge, agitate them. They are devoted, affectionate, grateful, prudent, circumspect, and cunning. Kindness soothes and melts them. Injury awakens their resentment. The movements of the brain, like those of the human encephalon, evokes in sleep their waking thoughts and desires. The dog of the chace dreams that he pursues the hare, and the more peaceful follower of the shepherd, that he collects the straying flock.

The intelligence of animals is rigorously limited to the objects of the external world that are presented to their senses. The intelligence of man has a far wider range. By the senses it is put in relation with the material world; by consciousness, with the inner being, the soul, and by intuitive ideas and sentiments with God.

The exalted intelligence of man confers on each individual a character as distinct as his features. He acquires from it his peculiar habits, qualities, tendencies, virtues, and faults. While it makes him free in one sense, it isolates him in another. Instinct, on the contrary, effaces individual distinction,—reducing all to a common type. All beavers, and all bees, lead lives absolutely alike, and may be regarded as differing no more than the units which make up an abstract number.

117. The inferior animals are endowed, as we have seen, largely with the powers of sensation, perception, and memory. They also possess, though in a very inferior degree, powers of comparison, generalisation, judgment, and foresight. In what then, it may be asked, consists the mark of the vast difference in degree of their intelligence, as compared with the mental powers exercised by the human race. This question has been satisfactorily answered by the observations and researches of Frederick Cuvier, Flourens, and others. According to these physiologists, animals receive by their senses impressions similar to those which are received by ours. Like us, also, they preserve and are able to recall the traces of these impressions. And such perceptions being thus preserved, supply for them as for us numerous and varied associations. Like us they combine them, observe their relations, and deduce conclusions from them, and to this extent, but not beyond it, their intelligence goes; but they have not a glimpse of that class of ideas which Locke denominates ideas of reflection. These, as is well known, are the perceptions which man acquires, not by his organs of sense, but by the power with which he is endowed to render his mind itself, and its operations, the subjects of contemplation and perception. Man has as clear a perception of the faculty of memory, for example, as he has of the colours of the rainbow. The scent of a rose is not more distinct to his apprehension than are his mental powers of comparison and induction. In short, his ideas of reflection are as vivid and definite as his ideas of sensation, and may, indeed, be said to be even more permanent and inseparable from his intellectual existence. He may be deprived of one or more of his

organs of sense, and thus cease to have any perception of the qualities peculiar to that organ, save those which his memory may supply. But so long as he exists and thinks, nothing can deprive him of the immediate perception of the ideas of reflection.

Of this class of ideas there is not the slightest trace in the inferior animals, and herein lies the line of demarcation which separates the human race from them, and places it immeasurably above them. Animal intelligence never contemplates itself, never sees itself, never knows itself. It is utterly incapable of that high faculty by which the mind of man, as Locke observes, "turns its view inward upon itself." That thought which contemplates itself; that intelligence which sees itself, and studies itself; that knowledge which knows itself, constitutes a distinct order of mental phenomena to which no inferior animal can attain. These constitute, so to speak, the purely intellectual world; and to man alone, here below, that world belongs. In a word, the animals feel, know, and think; but to man alone of all created beings it is given to feel that he feels, to know that he knows, and to think that he thinks.

118. Of all the instruments by which the range of intelligence is enlarged, and the power of reason augmented, language is assuredly the most important. It is the means by which feelings are expressed and knowledge imparted. It is the instrument by which the observation and experience of individuals is rendered common property.

Language, in the only sense in which it is an instrument of intelligence, is not the mere mechanical production of distinct sounds by the vocal organs, for in this sense parrots may be said to be endowed with it. It is a divine gift and not a faculty. Its origin has been sought for by the learned, but sought in vain. Like the instinct of self-preservation and reproduction, it has been an immediate emanation of divine power. God made it as he made light. He said, "Let man speak," and man spoke!

Most animals have voice, but man alone has language. It is by language, more than any other external character, that man is distinguished. The animals which come nearest to him in their physical organisation, such as the ourang-outang and other apes, are as completely deprived of language as those which are most removed from him. Man is thus separated from the lower animals by a bottomless abyss.

So important is language, as a means of extending the intelligence, that in a moral sense it may be said, that to speak or not to speak, is to be or not to be!

There can be no doubt in the mind of any careful observer, that the chief obstacle to the extension of the natural intelligence of many animals is the want of language to express their feelings and thoughts. It is evident that if the dog or the ourang-outang, which was the subject of Cuvier's experiments, could speak, their intelligence would be vastly enlarged.

Deprived of language, the more intelligent of the inferior animals seem, like the dumb, deeply conscious of the want, and make supernatural efforts to supply it and to make their sentiments understood. For this purpose they resort to ingeniously modulated vocal sounds, to signs and gestures. Each creature invents for itself a sort of pantomimic and highly expressive language. The dog appeals to you by gently laying his paw upon you, and if that fail to awaken your attention, he strokes you or taps you with it, as if he knew that you would thus be more apt to *feel* his solicitation. Does the cat desire to have some want supplied? she raises her back and passes her soft fur in contact with your legs, and repeats the application by going round and round you. The horse waiting at your door, fresh from his stall, and impatient for air and exercise, expresses his desire by pawing the ground with his fore-foot. In the pairing season, the male bird tries to fascinate his gentle mate by spreading out the fine hues of his plumage, making circuits, and fluttering around her.

All animals that have voice at all, use its modulations as a means of expression, and render it manifest that they would speak if they could. Many and ingenious are the artifices which they use as a substitute for the admirable instrument of intercommunication with which man has been gifted.

119. Thus, for example, in the case of such mammifers and birds as usually assemble in herds or flocks, individuals are observed who, being placed as sentinels, warn their companions of the approach of danger.

Marmots and flamingoes present examples of this. It is also observed with swallows, who, when their young are menaced by an enemy, immediately call together, by their cries of distress, all the swallows of the neighbourhood, who fly to the aid of their fellows, and unite to harass the animal whose attack they fear.

120. It has been well ascertained that various species of insects have means of intercommunication. The observations of Huber, Latreille, and other naturalists, leave scarcely a doubt on this point. Thus, for example, when an ant's nest has suffered any local disturbance, the whole colony is informed of the disaster with astonishing rapidity; no appreciable sound is heard, but the particular ants who are witnesses of the fact, are seen running in various directions among their companions. They bring their heads into contact, and unite their antennæ as two persons

would who take each other by the hand. All the ants who are thus addressed are immediately observed to change their route if they were moving, and to abandon their occupation if they were at work, and to return with those from whom they received the information, to the scene of the disaster, which is soon surrounded by thousands of these insects, thus brought from a distance.

121. In the wars which the population of two neighbouring ant-hills wage with each other, scouts and outposts precede the main body of the enemy, who often return to the leaders, giving them information, the consequence of which is, a total change in the order of march. In cases where these conflicts become doubtful, and that an army finds itself in danger of defeat, the leaders are often seen to detach aides-de-camp, or orderly officers, who return in all haste to their ant-hill, to bring up reinforcements, which assemble without delay, and march to join the main body of the army.

122. Large as the range of action is, which admits of explanation either by intelligence or instinct, or by the combination of both these faculties, some acts still remain of an extraordinary character which cannot be thus explained, and which would seem to imply the existence of some faculty in certain species of inferior animals of which man is totally destitute.

123. Among these may be mentioned the curious power with which certain birds, such as pigeons and swallows, are endowed; who, after being transported in close boxes to many hundred miles from their nest, take flight upon being liberated, and without the least hesitation direct their course towards the place from which they had been taken, with a precision as unerring as if it were actually within their view. In the case of dogs, and other mammifers, who having been brought to a great distance from home find their way back, the act is explained by the extreme delicacy of their sense of smell; but no such explanation will be admissible in the case of carrier-pigeons, who, having been brought, for example, from London to Berlin, and being liberated at the latter city, instantly direct their course back to the former, flying over the great circle of the earth which joins the two places. We are not aware that any attempt has been made to refer this class of facts to any recognised faculty.

124. Closely connected with instinct and intelligence is the capability of animals to be tamed and domesticated.

Naturalists agree generally that the animals which are domesticated with greatest facility are those which in the wild state live in troops or societies. To this there is scarcely a well-established exception. The cat and the pig are apparent exceptions, but it is contended that they are never domesticated in the true sense of the term. Every one is familiar with the difference between the domestic state of the cat and that of the dog. The latter is domesticated in the truest sense of the term.

A careful distinction must be maintained between the state of *tameness* and that of *domesticity*. The species of animals which are susceptible of these states are wholly different.

Domesticity descends from the parent to the offspring. Slavery here descends as an heritage.

Tameness is produced in the individual by the immediate treatment of man. The offspring of a tame bear would be as wild as the parent was before its subjugation.

The young of tame animals must, like the parents, be tamed. The young of domestic animals are already domestic.

Gregarious animals, endowed as they are with the instinct of sociability, select by common consent a chief, to whom they yield obedience. In the domesticated state, man taking the place and exercising the influence of that chief, receives the same instinctive obedience. Domesticity is, therefore, an animal instinct, of which man avails himself to attract into his service animals of the sociable species.

Tameness, on the contrary, is not an instinct but a habit. It is produced originally by fear, and maintained by the creation of artificial wants which man alone can satisfy.

Frederick Cuvier relates an incident which strikingly illustrates the distinction between the true instinct of sociability and the fictitious state of tameness produceable by habit.

A lioness, in the menagerie of the Garden of Plants, had been reared in the same cage with a dog. The two animals became familiar friends, and a mutual attachment was manifested. The dog having died, was replaced by another, which the lioness readily enough accepted and adopted, appearing to suffer nothing from the loss of her old friend and companion. In the same manner she survived the second dog, showing no signs of grief, and as readily as before received a third dog, with whom she continued to associate in the same manner. This third dog, however, outlived the lioness. When the latter died, a touching spectacle was presented. The poor dog refused to leave the cage in which the body of his friend lay. His melancholy increased from day to day. The third day he refused all food, and on the seventh died.

The agencies by which man first tames and later domesticates animals are few and obvious. They consist chiefly of the alternate privation and satisfaction of their physical appetites, and especially of those fictitious appetites which man himself excites and creates, and which he alone can gratify.

Hunger holds the first and most important place among these. It is by playing upon this appetite that the horse is tamed and trained. But little food is given at a time, and even that only at long intervals. The animal, ignorant that he who tends him is the cause of his privation, has full knowledge that it is by him that this privation is relieved, and if some choice aliment exciting to the palate is occasionally supplied, the authority of the master is augmented, and the gratitude and affection of the animal strongly awakened. It is by certain dainties, and especially by sugar, judiciously supplied and withheld, that the horses of the circus are brought to perform feats which create such general astonishment.

Privation of sleep is an agent of subjugation even more potent than hunger; and it is by hunger, pushed to excess, by the application of the whip, by stunning and alarming noises, such as those of the drum, and certain wind instruments, that this forced wakefulness is maintained.

By such means the urgent wants of the animal are excited; the power of the master is, however, acquired, not by the wants themselves, but by exhibiting himself in the most unmistakeable manner to the suffering creature as the agent of its relief. Not satisfied with presenting himself as the agent for the relief of real physical wants, he artfully creates fictitious ones, not only physical but moral. Choice food is now and then given, which none but the master can supply; but besides this the animal is rendered sensible to caresses, and after a time becomes most grateful for them. The elephant, the horse, and the cat are passionately sensible of the kindness of those with whom they are domesticated, but it is over the dog, more than any other, that the sway of this moral power extends.

A female wolf, in the Garden of Plants at Paris, became so sensitive to the caresses of its keeper, that it testified a delirium of joy at the sound of his voice or the touch of his hand. A Senegal jackal betrayed like emotions excited by a similar cause, and a common fox was habitually so affected by the caresses of its keeper that it was found necessary to discontinue such excitement.*

The process of subjugation of the wild animal is then one which attains its object by address and seduction. Natural wants are made to be felt, and fictitious ones are created, that man may have the merit of supplying them. He thus renders himself more

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* Mem., Fred. Cuvier.

and more necessary by the benefits he confers; and having arrived at that point, he ventures to employ fear and chastisement, which if resorted to without the previous measures would have excited resistance and repugnance.

To tame an animal is not to train him. Tameness is the subjugation of those instincts which would render him hurtful to those around him. Training is directed to the intelligence rather than the instinct. It is an educational process, which develops intelligence while it weakens instinct. Savages, while they are less intelligent than the civilised, have surer and quicker instincts. It is the same with the lower animals. Domesticity always enfeebles and often wholly effaces instinct.

When man educates and trains an animal, he imparts to it a ray of his own intelligence. The change is rather that of a new faculty created than of an existing one enlarged. It is a transformation rather than an improvement.

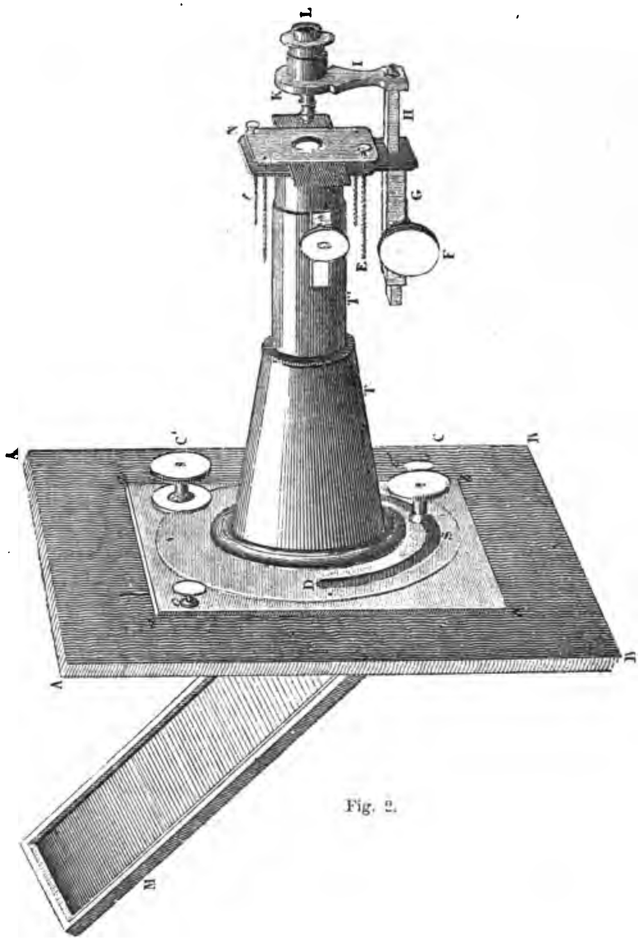


Fig. 2.

THE SOLAR MICROSCOPE.

1. Its utility.—2. The principle of its performance.—3. Why the magic lantern does not serve the same purposes.—4. The illuminating apparatus.—5. How to protect the object from heat.—6. The amplifying apparatus.—7. The adjustments.—8. The screen.—9. The reflector.—10. Method of mounting the instrument.—11. Arrangements for the room of exhibition.—12. Preliminary adjustments.—13. The oxy-hydrogen and electric microscopes.

THE SOLAR MICROSCOPE.

1. As an instrument for popular and general instruction, the solar microscope holds a high place. Until recently, its use has been restricted in these climates, by the circumstance of bright sunshine, and a room having a suitable aspect, being conditions indispensable for its performance. But by the substitution of the oxy-hydrogen light, and more recently still, of the electric light, the utility and pleasure derivable from this instrument of popular illustration have been immensely extended.

2. The principle of the solar microscope is the same as that of the magic lantern, and we must, therefore, refer the reader to our Tract upon that subject, for many details, to save the necessity of their repetition. The instrument consists of two parts, essentially distinct one from the other: the first, the illuminating; and the second, the magnifying part. Since it is desired to exhibit a very enlarged optical image of a very minute object, and since the light which is spread over the image can only be that which falls on the object, it is evident, that the brightness of the image will be more faint than that of the object, in the exact proportion in which the surface of the former is greater than that of the latter. To illustrate this, let us suppose that the object exhibited is an insect, a quarter of an inch in length, and that it is magnified 40 times in its linear dimensions, the length of the optical image will then be 10 inches, and its surface will be 1600 times greater than that of the object. The light, therefore, which illuminates the object, supposing the whole of it to be transmitted to the optical image, being diffused over a surface 1600 times greater, will be 1600 times more faint. But, in fact, the whole of the light never is transmitted, a considerable part of it being lost in various ways in passing from the object to the screen. The necessity, therefore, for very intense illumination in this instrument must be evident.

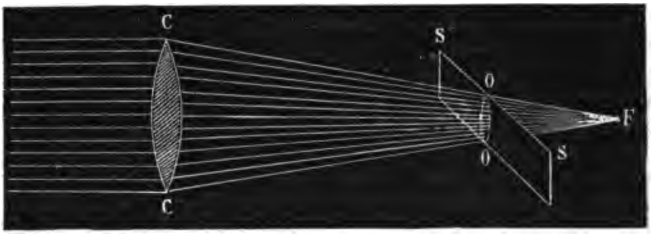
3. If these conditions were not borne in mind, it might appear that a magic lantern might be converted into such a microscope, by merely increasing the magnifying power of the lenses; but the light of the lamp, which is sufficient to illuminate a picture magnified 10 or 12 times in its linear, and, therefore, from 100 to 144 times in its superficial dimensions, would be utterly insufficient, if it were rendered 1600 times more feeble.

4. The illuminating apparatus of the solar microscope consists of a large convex lens, upon which a cylindrical sunbeam of equal diameter is projected. This lens causes the rays of such a sunbeam to converge to a point, and they are received upon the object to be exhibited before their convergence to a focus, and at such a distance from the focus, that the entire object shall be illuminated by them. In fact, the rays may be considered as forming a cone

which is cut at right angles to its axis by the slider upon which the object is fixed.

Let C C, fig. 1, be the condensing lens; let F be the focus to which the rays would be made to converge, but being intercepted by the slider S S, they are collected upon the small circular opening O O in the slider, and in this circular opening the small microscopic object to be exhibited is mounted between two thin plates of glass.

Fig. 1.



Now, it is evident, that the intensity of the light thus projected upon the object will be greater than that with which it would be illuminated without the interposition of the lens C C, in the exact proportion of the surface of the lens C C to the surface of the circular opening O O. Thus, for example, if the diameter of the lens C C be 5 inches, and the diameter of the opening O O half an inch, the diameter of the lens will be 10 times, and, therefore, its surface 100 times greater than that of the opening O O. In that case the object would be illuminated with a light just 100 times more brilliant than if the sun's light fell directly upon it, without passing through the lens C C.

It is found convenient in some cases to condense the light by means of two lenses. The cone of rays proceeding from C C might be received upon another condensing lens, by which its convergence might be increased. The advantage of this arrangement is that the distance of the object from C C, and therefore the length of the microscope, is rendered less than it otherwise would be.

5. There is, however, one practical inconvenience to be guarded against in this arrangement. The lens C C, which condenses the sun's light upon the object, also condenses its heat, and if the same object be exposed in the instrument for any considerable time, it would thus be injured or destroyed. This inconvenience may be obviated by the interposition of certain media, which, while they are pervious to the sun's light, are impervious to its heat; such media are said to be athermanous.*

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* From the Greek negative α (a) and θέρμη (thĕrmè) heat.

By the interposition of such a medium, the object may be prevented from receiving any increased temperature whatever.

It happens that water, which is the most convenient medium for this purpose, is very imperfectly pervious to heat, and is rendered almost completely athermanous by dissolving in it as much alum as it is capable of holding in solution. The object, therefore, is perfectly protected from the effects of heat, by placing between the slider and the condensing lens a cell, consisting of two parallel plates of glass, fixed at about an inch asunder, and filled with such a saturated solution of alum. The light intercepted by this is altogether inconsiderable, while the whole of the heat is stopped by it.

6. The magnifying part of the solar microscope consists of an achromatic lens, or combination of lenses, of very short focal length; this being brought before the object, at a distance from it a little greater than its focal length, will produce a highly magnified optical image of the object, upon a screen placed at a proper distance before it.

In the case of the magic lantern, it is not indispensable to incur the expense of achromatic lenses, and even the expedients to correct the spherical aberration are but little attended to. The magnifying powers used in that instrument not being great, and the objects exhibited not requiring extreme accuracy of delineation, the expense which would be incurred in producing large lenses free from the aberrations is not necessary. But in the case of microscopic objects, where great magnifying powers are applied, lenses in which the aberrations are not corrected would produce images so confused and indistinct as to be altogether useless. Achromatic combinations, therefore, in which the spherical aberrations are also corrected, are in this case indispensable.

As in the magic lantern, the same lenses may be applied, so as to produce different magnifying effects. If the distance of the lenses from the object were so great as twice their focal length, the image would be projected upon the screen at a distance in front of the lens also equal to twice its focal length, and would in that case be exactly equal to the object, and consequently there would be no amplification at all. As the lenses, however, are moved nearer to the object, the distance at which the image would be formed and its magnitude would be increased, and this increase would go on without practical limit, until the distance of the lens from the object would become equal to its focal length, in which case the image, having been enlarged beyond bounds, would altogether disappear.

In practice, therefore, the focus of the lens is brought to such a distance from the object, that the image upon the screen shall have a magnitude sufficient for all the purposes of exhibition. It is not desirable, however, in any case, to push the amplifying power of the instrument too far, because the illumination of the image in that case becomes inconveniently faint; and if there be any causes of aberration uncorrected in the lenses, whether spherical or chromatic, their effects will be rendered more apparent.

7. In the mounting of the instrument, provisions are necessary for varying, within certain limits, the distance of the object, as well from the illuminating as from the amplifying lenses. If the object be very minute, it is necessary that it should be illuminated with proportionate intensity; and, therefore, that it should be moved very near to the focus of the illuminating lens, C C. If it be larger, this position would, however, be unsuitable, inasmuch as the light would be collected upon a small part of it, to the exclusion of the remainder. In that case, therefore, the object must be brought farther in advance of the focus, F, of the illuminating lens, so as to intersect the cone at a point of greater section, and thus to receive a light which, though less intense, will be diffused over its entire surface.

The amplification required will be greater in proportion as the object is smaller. For very minute objects, therefore, the amplifying lens must be brought nearer to the object, and the screen must be removed farther from it, while for larger objects, the arrangement would be the reverse.

8. All that has been said on the subject of the screen in the case of the magic lantern will be applicable to the solar microscope, except that, in this case, the method of showing the object through a transparent screen is objectionable, because of the light which is lost by it, and for other reasons; and, besides, it is useless, that method of exhibition being adapted only for phantasmagoria, and other similar subjects of amusement.

9. In what has been explained above, it has been assumed that a beam of solar light is thrown upon the condensing lens C C, in the direction of its axis. Now it is evident that it could never happen that the natural direction of the sun's rays would coincide with that of the axis of the tube of the microscope; for, that axis being necessarily horizontal, or nearly so, the sun to throw its rays parallel to it should be in the horizon. Some expedient, therefore, is necessary, by which the direction of a sunbeam can be changed at will, and thrown along the axis of the tube.

The obvious method of accomplishing this is by means of a plate of common looking-glass; such a plate being conveniently mounted in front of the condensing lens, may always have such a position given to it that it will reflect the sunbeam which will fall upon it in the direction of the axis of the tube.

But since, by reason of its diurnal motion, the sun changes its position in the heavens from minute to minute, the position of the reflector, which at one time would throw the light in the proper direction, would cease to do so after the lapse of a short interval. A proper provision must be made, therefore, by which the position of the reflector may be changed from time to time with the motion of the sun in the firmament, so that it shall always reflect the light in a proper direction.

10. A perspective view of the solar microscope, mounted in the most efficient manner, is given in fig. 2; but the principle of its performance will be more easily understood by reference to the sectional diagram in fig. 3, where C C is the condensing lens, H H the mirror which receives the sun's light, and reflects it in the direction of the axis of the tube. This mirror turns on a hinge, by which it may be inclined at any desired angle to the axis of the tube; and a provision is also made by which it can be turned round the axis, so that its plane may be presented in any desired direction to the sun: a smaller condensing lens is interposed, upon which the rays, converging from C C, are received, and by which, with increased convergence, they are projected upon the opening O O in the slider S S, in which the object is mounted.

The tube in which the slider S S is inserted, and which carries the smaller condenser, slides within another tube, in the end of which the greater condenser C C is set. By this arrangement, the section of the cone of light, which falls upon the opening O O, may be varied, according to the magnitude of the object.

The amplifying lens, or lenses, L L, are conveniently mounted in a tube, which can be moved within certain limits to or from the object, so as to accommodate the focus to the position of the screen I I, upon which the image is projected.

After these explanations, the reader will have no difficulty in comprehending the instrument, as shown in perspective in fig. 2.

A board, A A B B, is pierced by a large circular aperture, the diameter of which is a little greater than that of the larger condensing lens; a square brass plate, *a a b b*, to which the microscope is attached, is screwed upon this board in such a position, that the condensing lens shall be concentric with the hole in it, and, consequently, that the axis of the instrument shall be at right angles to the board.

The plane mirror M, by which the light of the sun is reflected along the axis of the instrument, is mounted outside the board A′ A B B, moving on a hinge, as already described; and screws are provided at C C′, by means of which its inclination to the axis of the microscope can be varied at pleasure, and also by which it can be turned round the axis, the screw which governs its motion moving on the circular opening S D. By these means, whatever be the position of the sun in the heavens, such a position can always be given to the plane of the mirror, that the light may be reflected along the axis of the microscope.

The great condensing lens is set in the larger end of the conical tube T, and the lesser in the end of the cylindrical tube T′; the latter tube being moved within the former by an adjusting screw, which appears at its side. By the second condensing lens, the light is collected upon the opening in the slide, which is held between two plates N, pressed together by spiral springs.

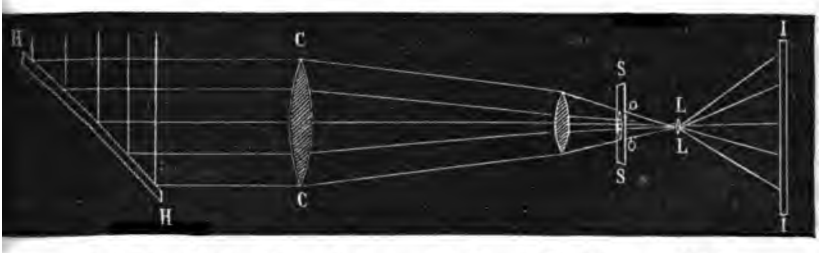
The tube T′ consists of two parts, one moving within the other, like those of the telescope.

The amplifying lenses are mounted in a brass ring, K, carried by the upright piece, I, so that its optical axis shall coincide with that of the illuminating apparatus. This optical part can be moved to and from the object, by means of a rack and pinion, F, attached to the piece H, which slides in the box G.

The structure and principle of the instrument being understood, it only remains to explain the method of using it.

11. The room in which the operations are conducted should have sufficient depth to allow the space between the microscope and the screen, which is necessary for the formation of an image of the required magnitude. This space will vary with the magnifying power required, but in general 10 or 12 feet beyond the nozzle of the instrument is sufficient. The room should be rendered as dark as possible, to give effect to the image, which, however well illuminated, is always incomparably less bright than would be objects receiving the light of day. The window-shutters should therefore be carefully closed, and all the interstices between them stopped. If the room be provided with window-curtains, they should be let down and carefully drawn. In a word, every means should be adopted to exclude all light, except that which may enter through the microscope.

Fig. 3.



An opening being provided in a convenient position in one of the window-shutters, corresponding in magnitude with the aperture in the board AA BB, the latter is screwed upon the window-shutter, so that the two openings shall coincide. The mirror M will then be outside the window-shutter, while the instrument and its appendages will be inside. The window selected should, of course, be one having such an exposure that the sun's rays can be reflected by the mirror in the direction of the axis of the tube.

12. To adjust the instrument, remove the piece N, which supports the slider, so that the light may pass unobstructed to the amplifying lens. By varying the position of the reflector M, by means of the milled heads C C′, a position will be found in which a uniformly illuminated disc will appear on the screen; this disc may be rendered more clear and distinct by adjusting the instrument by means of the rack and pinion attached to the tube.

When these preliminary adjustments are made, the piece N is replaced, and an object inserted in it; the instrument being then more exactly focussed, a distinct image of the object, upon a large scale, will be seen on the screen.

The management of the instrument will vary with the nature of the object. If it be a very transparent one, a strong light thrown upon it would cause it almost to disappear. The light, therefore, in such case, must be so regulated as to produce the image in the most favourable manner, which may always easily be accomplished by moving the tube T′ in and out of the tube T, until the desired result is obtained.

When the experiments are continued for any considerable interval, it will be necessary, from time to time, to accommodate the reflector M to the shifting position of the sun, which may always be done by the milled-heads C C′. This adjustment, however, might be superseded by mounting the mirror M upon an apparatus called a Heliostat, the effect of which is, to make the mirror move with the sun, by means of clock-work. Such an apparatus, however, is expensive, and the adjustment above described is attended with no great inconvenience or difficulty.

13. The substitution of the oxy-hydrogen, or electric light, for the sun in this most instructive instrument, renders those who use it, however, altogether independent of the sun, so that it can be used for a night as well as a day exhibition. Since the method of applying to it the electric light has been already described very fully in our Tract upon the Magic Lantern, the explanation need not be reproduced here.

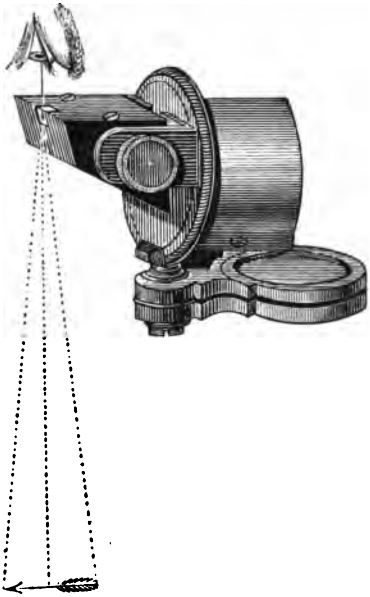


Fig. S.

THE CAMERA LUCIDA.

1. Origin of the name.—2. Its use.—3. Method of applying it.—4. Explanation of its principle.—5. Precautions in using it.—6. Methods of correcting the inversion of the object.—7. Amici's Camera.—8. Magnitude of the picture.—9. Application of Camera to the microscope.

1. This instrument, which takes its name by contrast from the camera-obscura, is one of the many gifts of the genius of Dr. Wollaston to the arts.

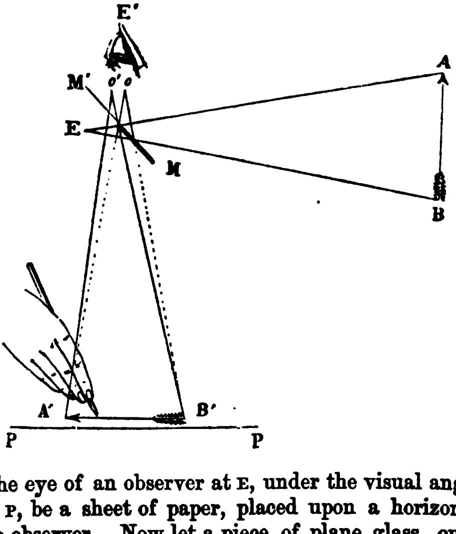
2. Like the camera-obscura, its chief, though not its only use, is to enable a draughtsman by the mere process of tracing, to make a drawing of an object.

3. The observer places upon its table, a sheet of drawing paper, and the instrument being placed level with his eye, he

looks into it, and sees the object to which it is directed, and at the same time sees, in the same direction, the sheet of paper which is upon his table, so that in fact, the object to be drawn, or its optical image, is seen projected and depicted on the paper. If he take in his hand a pencil, and direct it to the paper, as if he were about to write or draw with it, he will see his own hand and the pencil directed to the paper upon which the object is already optically delineated; and he will consequently be able, with the utmost facility and precision, to conduct the point of the pencil over the outlines of the object and those of every part of it, so as to make as correct a drawing of it as could be made by the process of tracing, in which a picture, placed under semi-transparent paper is traced by a pencil moving over its outlines.

4. To present the principle of this contrivance under its most simple point of view, let A B, fig. 1, be an object which would be

Fig. 1.



seen by the eye of an observer at E, under the visual angle A E B, and let P P, be a sheet of paper, placed upon a horizontal table before the observer. Now let a piece of plane glass, one half of which is silvered on the lower surface, be placed at an angle of 45°, with the direction in which the object A B is seen, so as to intercept the view of it from the eye at E; the rays of A E and B E, which encounter the silvered part of the glass, and which previously proceeded to E, will now be reflected to o, still, however, retaining the same divergence, so that they will enter the eye E' of the observer, supposed to look downwards at o, as if they had proceeded from A′ B′. In this manner the observer, looking from E′ towards the table, will see an image of the object at A′ B′, the point A′ of the image which corresponds with the top of the object being nearest to him, and the point B′, which corresponds with the bottom, being farthest from him; so that, in effect, the image will appear inverted.

Now suppose two lines, A′ o′ and B′ o′, drawn from the extremities of the image A′ B′, to a point o′ very near to o, and so as to pass through that part of the glass M M′ which is not silvered. An eye looking from o′ would then see the part of the paper upon which the image A′ B′ is projected, and would also see a pencil held in the hand of the draughtsman directed to the paper.

If the distance between the points o and o′ be less than the diameter of the pupil of the eye, the observer looking down from E′ will see at the same time, and in the same position, the image A′ B′ and the part of the paper corresponding with it,—for he will see the image by the rays which converge to o, and the paper by those which converge to o′; the effect, in short, will be that he will see the image as if it were actually projected upon the paper.

If the eye be advanced towards the mirror, so far as to cause the limiting ray A′ o to graze the lower edge of the pupil, the paper will be altogether intercepted by the silvered part of the glass M M′, and the observer, though still seeing the image of A B reflected in the glass, will no longer see it on the paper, and for the same reason, he will see neither his hand nor the pencil, and he cannot of course make the drawing.

If, on the contrary, the eye be moved from the glass so far as to cause the limiting ray A′ o to graze the upper edge of the pupil, the image of A B reflected from M M′ will altogether disappear, and nothing but the hand and the pencil will be seen, these last being visible through the unsilvered part of the glass.

5. It is evident, therefore, that in order to enable the eye to see the entire image projected on the paper, it must be held in such a position, that while the limiting ray B′ o′, shall pass within the lower edge of the pupil, the limiting ray A′ o shall pass within its upper edge. That this may take place, it is necessary that the distance between the points o and o′ shall not exceed the diameter of the pupil, and that the eye be steadily held, so that o and o′ shall be both within the pupil.

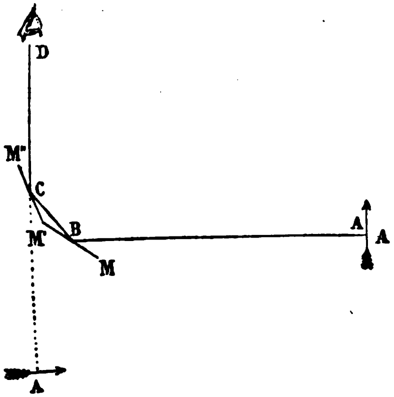
Since the average diameter of the pupil is two-tenths of an inch, it follows that the distance between the points o and o′ should not exceed that limit, and that any displacement of the head which would displace the eye through the space of two-tenths of an inch, would remove from view the pencil or image, partly or wholly.

It will be easy from these considerations to appreciate the difficulty of using this instrument, and the necessity for practice and patience from those who expect to acquire facility and expertness in its management.

6. The inversion of the object produced by the reflector M M′, being inconvenient, a modification of the instrument was contrived, which gives an erect image; this is accomplished by the easy and obvious expedient of subjecting the rays proceeding from the object to two successive reflections, the first of which, as described above, would give an inverted image, which being itself inverted by the second, gives an erect image of the object.

This is effected by two plane reflecting surfaces M M′ and M′ M″, fig. 2, placed at an angle with each other of 135°; the one M M′ being inclined at 22½°, with a horizontal line, and the other at the same angle with the vertical line. A ray A B, coming horizontally from the object, will fall upon M M′ at an angle of 22½°, and being reflected at the same angle, will fall upon M′ M″, still at the same angle, being reflected from it, in the vertical direction, C D. An object A, after the second reflection, will therefore be seen erect upon a level surface, before a draughtsman who stands with his face towards A, and stooping over the reflector M′ M″, sees the image of A in it.

Fig. 2.



In some forms of the instrument, the reflections are made by a prism, on the principle explained in "Optical Images," (24.) Thus if one reflection only be used, a rectangular prism is applied, as shown in fig. 3, the ray A B from the object entering the face of the prism perpendicularly, and being reflected at B to the eye at C.

If two reflections be used, a quadrangular prism, having two

Fig. 3.

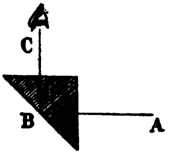
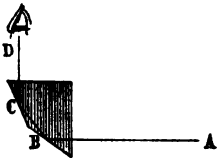


Fig. 4.



angles of 67½°, one right angle, and one of 135°, is applied, as shown in fig. 4. The course of the ray from the object to the eye being A B C D.

In the preceding cases, we have supposed the observer to see the object by reflection, and the paper and pencil directly; but it is evident that the conditions may as easily be reversed, so that the object may be seen directly, and the paper and the pencil by reflection. Thus we may suppose the plane mirror M M′ in fig. 1, to be silvered in the upper instead of the lower surface, and the observer looking from E horizontally to see the object directly through the unsilvered part, while he sees the paper and pencil by the reflection from the silvered part.

This method is in many cases found more convenient than that first described.

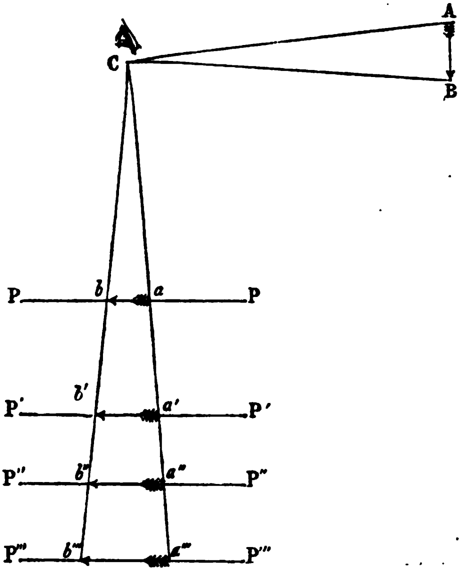
7. In some forms of the instrument, the observer looks at the object through a small hole made in a plane reflector, placed at an angle of 45° in the direction of the paper; the diameter of the hole being less than that of the pupil. In this case, while the object is seen directly through the hole, the paper and pencil are seen by reflection from the surface of the reflector surrounding the hole; this is the form of the camera-lucida applied to the microscope by Professor Amici.

8. Whatever be the form of the camera, the visual magnitude of the image projected on the paper as seen by the eye applied to the instrument, is the same as the visual magnitude of the object seen directly, and this will be the case at whatever distance from the camera the paper may be placed. It follows from this, that the actual magnitude of the picture projected on the paper will be greater or less according to the distance of the paper from the camera, and that consequently the observer, by regulating the

distance of the paper, can obtain a picture of the object on any scale he may desire.

To render this more apparent, let C, fig. 5, be the place of the camera, and A B the object, whose visual angle will therefore be A C B. If the paper be placed at P P, the lines C *a* and C *b*, drawn to the extremities of the image upon it, will make the angle *a* C *b* equal to A C B, so that the visual angle of the image *a b*, will be equal to that of the object A B.

Fig. 5.



If the paper be now removed to P' P', the visual lines C *a*, C *b*, continued to it at *a' b'*, will still be those which mark the extremities of the image, whose visual magnitude will therefore be measured by the same angle. But the space which the image covers on the paper at P' P', or what is the same, the actual length of the optical picture on the paper, will be greater than at P P, in the proportion of *a' b'* to *a b*, or what is the same, to the distance of P' P' to that of P P from C.

In the same manner it will appear, that if the paper be successively moved to greater distances, such as P'' P'', and P''' P''', the picture will be magnified in its linear dimensions, in the exact proportion in which its distance from the camera is increased.

9. One of the most recent and beautiful applications of the camera-lucida, is its adaptation to the compound microscope, by means of which, details and lineaments of objects, so minute as to escape ordinary vision, are depicted with a precision and fidelity only surpassed by the results of photography.

The instrument is fixed upon the eye-piece of the microscope, in such a manner, that while the observer looks directly through the eye-glass at the object, he sees the paper and pencil by reflection, the latter being placed upon the table before him. Supposing the axis of the microscope to be horizontal, the paper and pencil will be reflected from a plane mirror placed at an angle of 45° with the vertical, the reflecting side being turned downwards.

The instrument may be so arranged, that the paper may be seen directly, and the object by reflection. In this case, the mirror is also placed at 45° with the vertical, but the reflecting side is presented upwards. The rays, proceeding through the eye-glass from the object, are reflected upwards and received by the eye of the observer, which, looking downwards, views the paper directly.

In figs. 6 and 7, is shown the arrangement by which the observer O, views the object directly through a small hole in the oblique reflector, which is fixed upon the eye-piece, while he sees the paper and pencil by two reflections, the first from the back of the prism P, and the second from the oblique reflector M *m*. The effect is to project the image of the object seen in the microscope V, upon the image of the paper seen in the reflector M *m*.

Fig. 6.

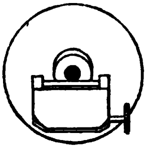
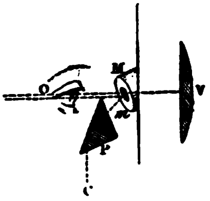


Fig. 7.



The prism P is interposed in this case to render the image of the hand and pencil erect; a front view of the prism and eye-piece is shown in fig. 6, and a side view in fig. 7.

In fig. 8, an arrangement is shown by which the object is seen by reflection, and the paper directly.

In this case the rays issuing from the eye-piece of the microscope are reflected twice successively from the two sides of the prism, which are inclined to each other at an angle of 135°, as explained in (6).

According to what has been explained in (8), the observer can vary the magnitude of the picture on the paper by varying the distance of the paper from the prism, without varying the magnifying power of the microscope; and in this way he can make a tracing of the object on any desired scale.

Fig. 2.

THE MAGIC LANTERN.

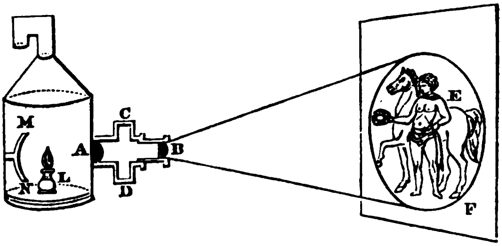
1. Optical principle of the instrument.—2. Its most common form.—3. Magnifying power.—4. Precautions to be taken in the use of the instrument.—5. Pictures on the sliders.—6. Opaque screen.—7. Transparent screen.—8. Phantasmagoria—method of producing it.—9. Exhibition with two lanterns.—10. Curious optical effects.—11. Dissolving views.—12. Application of the lantern to the purposes of instruction—in history and chronology.—13. In geology.—14. In astronomy.—15. Use of solar system.—16. Great utility of the lantern for this purpose.—17. Views of the stars.—18. Nebulæ and clusters.—19. Practical example of the utility of this instruction.—20. Oxyhydrogen lantern.—21. Application of electric light to the lantern.

1. The magic lantern is an optical instrument adapted for exhibiting pictures, painted on glass in transparent colours, on a large scale by means of magnifying lenses.

It has been shown (see "Optical Images") that when a picture, or other object, is placed in front of a convex lens, at a distance from it somewhat greater than its focal length, such picture or object will be reproduced upon a screen, placed at a certain distance behind the lens, that distance being greater the nearer the picture in front of the lens is to its principal focus. This is the principle upon which the magic lantern is constructed.

2. It varies in form and arrangement, according to its price and the circumstances under which it is used, but in general consists of a dark lantern fig. 1, within which a strong lamp L is placed, having a bent chimney at the top, to allow the smoke and heated air to escape, while the light is intercepted. In front of the lamp, and on a level with its flame, a tube is inserted, in which a large convex lens A is fixed, by means of which the light of the lamp is condensed upon the picture placed opposite the lens A, by sliding it through a groove, C D. From this mode of fixing the picture, the latter has generally been called a "slider." In the tube thus projecting from the lantern, another tube is fitted sliding in it, as one tube of an opera-glass slides in the other. At the end of this second tube a convex lens B is set, and the tube is so adjusted, that the distance of B from the picture shall be a little greater than the focal length of the lens B. A large screen F, made of white canvas, which is much improved by covering it with paper, is then placed at a distance from B, and at right angles to the axis of the lens. By properly adjusting the tube B, and the distance of the screen F, the picture upon the slider in C D will be reproduced at E upon the screen, on an enlarged scale.

Fig. 1.



It must be observed, however, that as the picture will be inverted, with relation to the object, it will be necessary to turn the slider in C D upside down, in order to have the picture on the screen in its proper position.

To increase the illumination of the slider, a concave reflector M N is usually placed behind the lamp, by which the light projected upon the lens A is increased. A better effect, however, may be produced by simply bending a sheet of white paper or paste board round the inside surface of the lantern.

3. With the same lantern, and the same slider, a picture of any desired magnitude can be produced. To increase the picture, it is only necessary to push in the lens B, so as to bring it closer to the slider, and to remove the screen F to a greater distance. But it must be remembered, that every attempt to enlarge the picture will not only be attended with greater indistinctness, owing to spherical aberration, and more appearance of colours at the edges of the figures, owing to chromatic aberration, but also the brightness of the picture will be greatly diminished, since it is evident that the greater the surface over which the light by which the slider is illuminated is diffused, the more faint, in the same proportion, will the picture on such surface be; and, since the magnitude of such surface increases in the same proportion as the square of its linear dimensions, it follows that when the picture has double the height or width, it will be four times less bright. (See Tract on "Optical Images.")

4. The body of the lantern should be large, so that it may not become inconveniently heated. The best oil should be burnt in the lamp, so as to diminish the smoke and disagreeable odour. The glass chimney of the lamp should be made as high as possible, and the wick should be of large calibre.

5. The pictures on the sliders should be as large as possible, in order to ensure sufficient illumination on the screen. With a given magnitude of picture on the screen, and a given force of lamp, the illumination will be proportional to the magnitude of the slider. If a small slider be used to produce a picture on the screen of a given magnitude, the confusion arising from both kinds of aberration will be greater than if a larger one were used.

6. There are two ways of exhibiting the pictures on a screen: in one, the lantern is placed in front of the screen, with the spectators; in that case the picture is seen by the light reflected from the screen, after having been projected upon it by the lantern.

Care should therefore be taken that no light shall penetrate through the screen, since all such light would be lost, and the picture on the screen would be proportionally more faint. A screen composed of muslin, or any other textile fabric, would in such case be defective, inasmuch as more or less of the light would penetrate it. The best sort of screen is one made of strong white paper, pasted on canvas, and stretched on a frame, as canvas is in a picture.

7. When the magic lantern is used for purposes of amusement, rather than those of instruction, it is generally found desirable to use a semi-transparent screen, the lantern being

mounted on one side of the screen, and the spectators placed on the other, as shown in fig. 2 (p. 193). In this case, the screen should be made of white muslin or fine calico stretched upon a frame, its transparency being increased by wetting it well with water. In some cases the muslin is prepared with wax or oil, which may be convenient to save the trouble of wetting it, but which in other respects does not answer the purpose better.

8. When the pictures are produced through a transparent screen, the exhibitor being concealed from the spectators, may make them vary in magnitude: first gradually increasing, and then gradually diminishing. This is accomplished by moving the lantern gradually and alternately from and towards the screen, varying the focus during the motion, so as to render the picture upon the screen always distinct.

Let us suppose for example, that the nozzle of the lantern is first placed in actual contact with the screen. The picture on the screen will then be exceedingly small, and the spectators, to whom the screen is invisible, will imagine the object to be at a great distance. Let the exhibitor then move back the lantern slowly from the screen, keeping the focus constantly adjusted, the picture on the screen will then be gradually enlarged, and the impression produced on the spectators will be that its increased magnitude is produced by the gradual approach of the object towards them; and so complete is this delusion, that the rapid increase of magnitude of the picture actually startles even persons who are most familiar with the optical causes which produce the effect. It sometimes appears as if the object would approach so as to come in actual collision with the spectator.

When the object seems thus to be brought near the spectator, it is made to retire gradually by moving the lantern towards the screen, the effect being produced by the gradual diminution of the image upon the screen, and this is continued until the nozzle of the lantern coming again in contact with the screen, the object seems again to be lost in the distance, its magnitude being reduced to a mere point. The exhibitor seizes this moment to change the picture, displacing one slider by the introduction of another, a manœuvre which, when adroitly performed, will escape the notice of the spectators. The new picture is then exhibited in the same way.

Effects of this kind have been denominated "phantasmagoria," from the Greek words *φαντασμα* (phantasma), *a spectre*, and *αγοραομαι* (agoraomai), *I meet*.

9. Interesting and amusing effects are produced by placing two lanterns of equal power, so as to throw pictures of precisely equal magnitude on the same part of the same screen. A sliding cover

is placed in front of the nozzle of each of the lanterns, and these are moved simultaneously in such a manner, that when the nozzle of one lantern is completely opened, that of the other is completely closed, so that, according as the former is gradually closed, the latter is gradually opened.

10. To illustrate this class of effects, which always create an agreeable surprise, let us suppose that two sliders are placed in the lanterns, one representing a landscape by day, and the other representing precisely the same landscape by night, and let the nozzle of that which contains the day landscape be opened, the other being closed: the picture on the screen will then represent the day landscape. If the covers of the nozzles be now slowly moved, so that that of the lantern which shows the day landscape shall be gradually closed, and that of the other shall be gradually opened, the effect on the screen will be that the day-light will gradually decline, the view assuming, by slow degrees, the appearance of approaching night. This gradual change will go on, until the nozzle of the lantern containing the day picture has been completely closed, and that containing the night picture completely opened, when the change from day to night will be accomplished, the picture on the screen being then a night landscape.

An infinite variety of amusing effects of other kinds are contrived by accessories combined with such pictures. Thus, for example, a view, exhibiting a landscape in bright sunshine, becomes gradually clouded and obscure, and snow begins visibly to fall; the darkness increases, night comes on, the moon rises, illuminating the landscape, which now appears covered with snow. The wheel of a mill, which was moved by a stream, which seemed flowing in the sunshine, is now at rest, loaded with snow and icicles; the stream no longer flows, but is frozen.

All these effects are produced by two or more lanterns, the mill-wheel is a little metal-wheel attached to that part of the slider on which the mill is delineated, and kept in motion by wheel-work impelled by the hand of the exhibitor. The fall of snow is produced by a sheet of blackened paper, pierced with a multitude of little holes, and moved before the lamp by means of rollers at the top and bottom; the light passing through the holes forms white spots, which are projected on the screen, and which appear to fall like snow-flakes. The clouds pass over the sun or moon, or move from them so as to cover or unveil them, by the motion of a second slider behind the first.

Another class of appearances is produced by one of the exhibitors managing with address a small supplemental lantern. Thus, for example, the picture of a castle, with portcullis and drawbridge, is exhibited; the portcullis rises, and a knight in armour issues from it on horseback, and crosses the drawbridge.

The opening of the portcullis is in this case produced by a moveable plate attached to the slider representing the castle, and the figure of the knight is produced by means of a second lantern, so skilfully managed as to throw the image of the knight upon the screen, and to move it, so as to make it appear to cross the drawbridge.

11. The optical effect produced by two lanterns working together, called dissolving-views, with which the public has been rendered familiar, at several of the public institutions in London, depends on the alternate opening and closing of the nozzles of two lanterns, in the manner already described, the mistiness and confusion which is exhibited in the gradual disappearance of the one view, and the gradual appearance of the other, arises from the circumstance of the nozzles of both lanterns being partially open at the same moment, so that both views, faintly illuminated, are projected upon the screen at the same time. The mixture of their outline and colours produces the mistiness and confusion, with which all spectators of such exhibitions are familiar. According as the nozzle of the lantern which contains the disappearing view, is more and more closed, and that which contains the appearing view more and more open, the latter becomes more and more distinct, and becomes perfectly so, when the one lantern is completely closed, and the other is completely opened.

12. These, and innumerable other optical effects, are limited in their object to the mere purpose of amusement. Without rejecting such lighter use of the lantern, its possessors should not, however, forget that it is capable of infinitely more important uses. It may be made extremely useful in impressing upon the minds of young persons the most important events and epochs in history and chronology, by the exhibition of series of portraits and scenes accompanied by observations and comments upon them proceeding from an intelligent instructor. Its use in conveying general notions of natural history is well known. Paintings of the various classes of animals and plants are executed sufficiently well for the purposes of such instruction, and sold by the opticians at a very moderate price. The use of the lantern in this department might be considerably extended, if similar paintings of insects and animalcules, on a magnified scale, could be obtained; these being still more enlarged by the lantern, many of the effects of the solar microscope might be exhibited, and much instruction imparted.

13. In the same manner, the first notions of geology might onveyed by sections of the strata properly painted on the

sliders. It is obvious also that the fossil animals could be very advantageously presented in this way.

14. But of all the departments of instruction for young persons, that to which the magic lantern lends itself most happily is astronomy; and here the artists have already prepared admirable sets of sliders, which can be obtained at moderate prices, and convey, in a most pleasing manner, most important instruction. Thus, the annual and diurnal motion of the earth, with the vicissitudes of day and night, and the succession of the seasons, are executed by means of a slider provided with mechanical expedients for producing the several effects. In the same manner, sliders are adapted to show the effects of the sun and moon in producing the tides of the ocean; the motions of the planets round the sun; solar and lunar eclipses; the motions of comets, with the development of their tails, and in a word all the principal motions of the bodies composing the solar system.

15. A class of astronomical objects, which would supply highly interesting and instructive subjects of optical exhibition with the lantern, would be telescopic views of the sun, moon, and planets. The spots on the sun well delineated, as they might be, the remarkable lineaments of the moon, showing so conspicuously the inequalities of its surface, the peculiar appearances exhibited by the disc of Mars, on which the polar snow is visible, and the outlines of land and water faintly apparent, the atmospheres of Jupiter and Saturn, stratified by their atmospheric currents, so as to produce belts, the triple ring of Saturn, the motions of the satellites of Jupiter and Saturn, showing their eclipses, are severally phenomena which might easily be exhibited with the lantern. Some of these have been already attempted by the opticians, but in a manner that had better have been left alone. The telescopic views of the planets given upon the common sliders are worse than worthless, since they produce most erroneous notions. The view of the moon usually given is less objectionable; nevertheless, nothing would be more easy than to get proper sliders painted from good originals, which are easily obtained. Excellent telescopic views of Mars, Jupiter, and Saturn have been reproduced in my work on astronomy from the original drawings of Mädler, Herschel, and other authorities. I have given them on a scale such that they could be transferred to sliders without difficulty; Saturn with his rings I have also given from the original drawings of the most recent observers.

Various views might be given of different parts of the moon's surface, and of the solar spots; these I have also given on a proper scale from the originals of Pastorff, Mädler, Herschel, and others. Comets, with their extraordinary changes of form and appearance, would also form an interesting series of astronomical objects.

16. Those who have not practically tried the effects of such a mode of instruction can with difficulty imagine the extent and variety of information that may be imparted by it, the facility with which it is acquired, and the tenacity with which it is retained. For the acquisition and retention of knowledge there is no organ like the eye. The most able and clear-headed instructor, using his best exertions by oral instruction, will never impart so clear a notion of the motions of the heavenly bodies, or their telescopic appearance, as that which may be obtained by the ocular, even though silent lessons of the magic lantern. But if the exhibition produced by that instrument be accompanied by proper oral comment and exposition, there are no means of instruction with which I am acquainted, suitable to young persons, that can approach to it.

17. Passing beyond the solar system, the starry firmament supplies an endless series of objects for optical exhibition with the lantern. The pupil can with the greatest facility be rendered familiar with the constellations, and the teacher may make for himself the sliders. Let him provide three or four pins of different thicknesses, and let him mark upon thick paper or pasteboard the arrangement of the stars in each principal constellation, which he can easily do by the aid of any celestial maps, and for this purpose I would recommend Professor de Morgan's "Guide to the Stars." Having thus marked out the constellations, let him pierce, with the thickest of the pins, holes corresponding with the places of the stars of the first magnitude. In the same manner, holes for stars of the second magnitude will be pierced by the next sized pin, and so on. The paper thus pierced being pasted on slips of glass, may be used as sliders.

18. It is scarcely necessary to add, that telescopic views of the nebulæ and stellar clusters may be produced and applied in the same manner.

19. In recommending thus emphatically the magic lantern as an instrument of instruction for the young, I speak from practical knowledge of its effects, having applied it in the case of my own children, and obtained all the results which I have here indicated.

20. For family and school purposes, a good lamp is the most convenient means of illuminating the sliders; but where exhibitions are produced before larger and adult audiences, other and more effectual means of illumination are resorted to. For several years, the lanterns by which dissolving-views, and other effects, have been produced at the public exhibitions in London, have

been illuminated by the oxy-hydrogen light. The manner in which this illumination is produced will be explained more fully in another part of the MUSEUM. Meanwhile, we may briefly state here, that the light proceeds from a ball or cylinder of lime, which is rendered incandescent, or white-hot, by the flame of a blow-pipe, from which a mixture of oxygen and hydrogen gases, in the proportion in which these gases produce water, issues.

It might be imagined that the light produced by a piece of solid matter like lime, however intensely heated, could never be brilliant enough to produce a strong illumination; nevertheless, the light radiated from the lime in this case was the most intense artificial light which had ever been produced until the invention of another, which we shall presently notice.

In the oxy-hydrogen lanterns, the cylinder of lime is mounted, so as to occupy the place of the flame of the lamp in the axis of the lenses. The flame of the blow-pipe is projected upon that side of it which is presented towards the lenses, and since the lime, though it does not undergo combustion, is gradually wasted by the action of the flame, it is kept in slow revolution by clock-work, connected with the axis upon which it is supported, so as to present to the flame successively different parts of its surface.

21. This method of illumination, though still continued, is greatly surpassed in splendour by that of the electric light, which has recently been applied to the magic lantern by Mr. Dubosc, the successor of Mr. Soleil, the celebrated Paris optician.

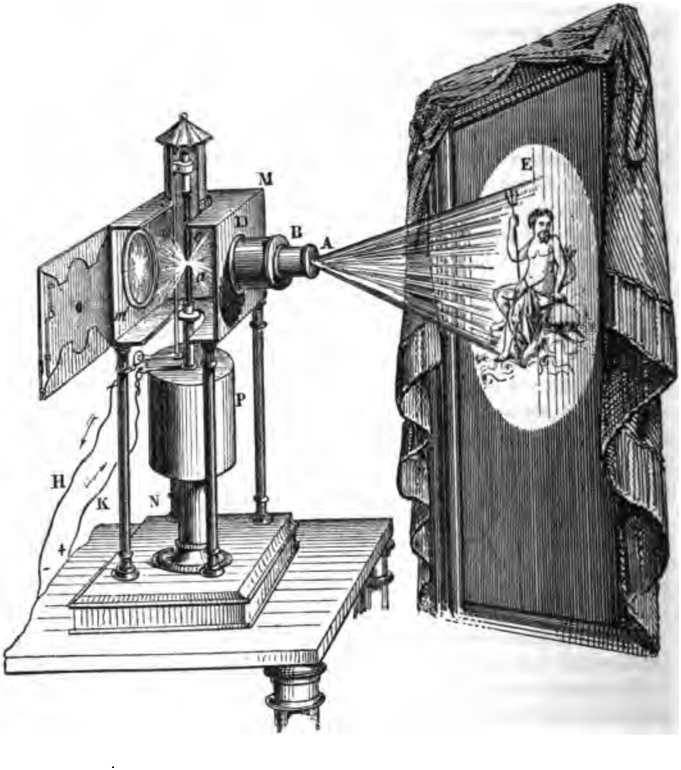
The electric light, which will be more fully described in another part of this series, is produced by bringing two pieces of charcoal, previously put in connection with the poles of a Voltaic battery, nearly into contact; the Voltaic current will then pass from one to the other, the ends of the charcoal thus nearly in contact becoming incandescent, and emitting the most brilliant artificial light which has ever yet been produced.

The method of mounting this illuminating apparatus in the lantern is shown in fig. 3.

The wires H K, being connected with the poles of the battery, are attached to two pieces of metal, the negative wire H communicating with the upper pencil of charcoal *c*, and the positive wire K with the lower charcoal pencil *a*. The points of the pencils being nearly in contact, the light will be produced in the manner just explained.

Although the charcoal does not, properly speaking, undergo much combustion, it is gradually wasted, and when the points would thus become separated, the current would be suspended, and, therefore, the light would cease. To prevent this, and to maintain the illumination, an apparatus consisting of clock-work is provided in the case P, by which the charcoal pencil *a* is kept nearly in contact with the pencil *c*. The clock-work is so constructed that its motion is governed by the current.

Fig. 3.



Mr. Dubosc has contrived the means by which a single electric light will serve to illuminate at the same time two lanterns, placed side by side for exhibition. This is accomplished by placing the light between two reflectors, so inclined that each reflects it in the direction of the axis of one of the lanterns.

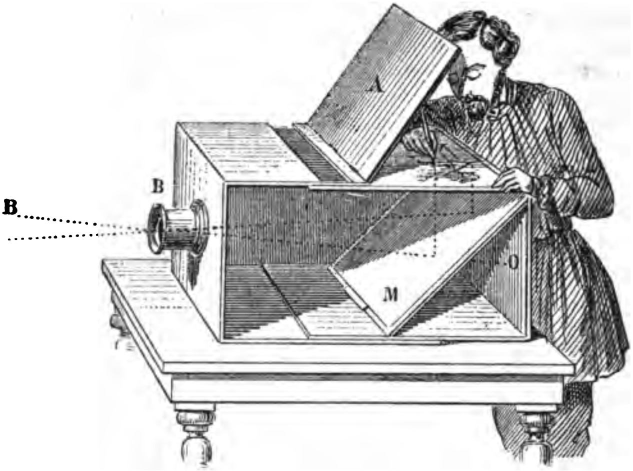


Fig. 4.

THE CAMERA OBSCURA.*

1.—Principle of the instrument.—2. Its inventor.—3. Method of mounting it.—4. Application of the prism to it.—5. Mounting a camera with prism. —6. Portable camera.—7. Form of camera adapted to photography.

1. This is an instrument of extensive utility in the arts of design; by it the process of drawing is reduced to that of mere tracing, and its use has of late been greatly extended by its application in the art of photography.

We have already explained, in our Tract upon "Optical Images," that if a convex lens, or any equivalent optical combination, be presented to a distant object, such as a landscape, an inverted image of that object, with its proper outline and colours, will be produced at the principal focus of the lens. Let us suppose, for example, that the window-shutters of a chamber being closed, so as to exclude the light, a hole be made in them, in which a convex lens is inserted: let a screen made of white paper be then placed at a distance from the lens, equal to its focal

---

* Two Latin words, signifying "a dark chamber."

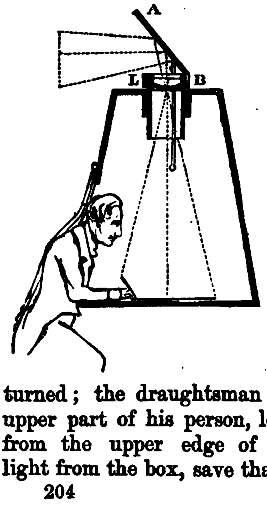
length, and at right angles to its axis; a small picture will be seen upon the screen, representing the view facing the window to which the axis of the lens is directed; this picture will be delineated in its proper colours, and all moving objects, such as carriages or pedestrians, the smoke from the chimneys, and the clouds upon the sky, will be seen moving upon it with their proper motions. The picture, however, will be inverted, both vertically and laterally, the sky being below and the ground above; trees and buildings will have their tops downwards, vehicles will move with their wheels, and pedestrians with their feet, upwards, objects on the right of the landscape will be on the left of the picture, and *vice versâ*, and all motions will be reversed in direction; objects moving to the left appearing to move to the right, and those which fall, appearing to rise.

2. This remarkable optical phenomenon was discovered in about the middle of the sixteenth century, by Baptista-Porta, a Neapolitan philosopher, and it was not long before it assumed a variety of forms, more or less useful; the name *Camera-Obscura* was given to it from the circumstances explained above.

3. A great variety of forms have been given to this instrument, varying according to the circumstances under which it is applied. One of the most simple of these is shown in fig. 1.

The lens, L, is inserted in an opening in the top of a rectangular box, the height of which is made to correspond nearly with its focal length; the bottom of the box is placed at a convenient height, to serve the purpose of a desk or table for the draughtsman; a sheet of drawing paper being placed upon it, will receive the optical picture of such distant objects as may be found in the direction of the axis of the lens. The lens is set in a tube, which slides in the opening made in the box, so that by moving it more or less upwards or downwards, the instrument may be brought into focus, and a distinct picture produced upon the paper. An opening is made in the box, at that side of it towards which the bottom of the picture is turned; the draughtsman introducing through this opening the upper part of his person, lets fall over him a curtain, suspended from the upper edge of the opening, so as to exclude all light from the box, save that which proceeds from the lens at the

Fig. 1.

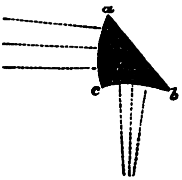


top. Thus placed, the draughtsman can trace the outlines of the picture.

But in the case here supposed, the axis of the lens being vertical, the picture would be that of the firmament. To obtain a picture of any part of the surrounding landscape, a plane mirror, A B, is fixed upon a hinge at B, and is regulated in its position by a handle which descends into the box, so that the draughtsman can give it any desired inclination. The effect of this mirror is indicated in the figure by the rays, which, falling upon it, are reflected downwards to the lens. It will be evident, from what has been already explained in our Tract upon "Optical Images," that when this reflector is properly adjusted, a picture of the landscape before it will be reflected towards the lens L B, and by it projected upon the desk of the draughtsman.

4. The oblique mirror A B, and the lens L, are sometimes replaced with advantage by a prism, such as that represented in fig. 2. The face, *a c*, of this prism, at which the rays coming from the landscape enter, being convex, these rays are affected exactly as they would be if they entered the convex surface, of a lens; when they fall upon the plane surface, *a b*, of the prism, they will be reflected from it, according to what has been explained in "Optical Images" (24); thus reflected, they will fall upon the other side, *c b*, of the prism; this side is ground concave, but its concavity being less than the convexity of the side *a c*, the effect of the two sides upon the rays will be the same as that of a meniscus lens, one side of which has the convexity *a c*, and the other the concavity *b c*. In such a lens the convexity prevailing over the concavity, the effect will be that of a convex lens.

Fig. 2.



The curvatures of the two sides of the prism are so regulated that its focal length shall correspond with the height of the box.

5. One of the methods of mounting a camera constructed with such a prism, is shown in fig. 3. The prism is mounted in a case, upon a horizontal axis, and its inclination is regulated by milled heads, like the heads of screws, on the outside; the case on which it is mounted has an opening through which the rays proceeding from the landscape are admitted; and it can be turned round its vertical axis, so that the opening can be presented in any direction to the surrounding landscape. The apparatus is supported by a triangle, and the draughtsman is surrounded by a curtain, forming a tent, from which the light is sufficiently excluded. The height of the tent, relatively to the table, is of course regulated according to the focal length of the prism.

6. Another variety of mounting for cameras is shown in fig. 4 (p. 203). This, which is one of the most portable forms of the instrument, consists of a rectangular case, composed of two parts, one of which slides within the other like a drawer; in one end is placed the lens B, in the other a plain mirror M, inclined at an angle

Fig. 3.

of 45° to the top of the box. Over this mirror is a lid A, movable on hinges, under which in the opening is set a square plate of ground glass; the lid A is provided with arrangements by which it can be fixed at any desired inclination to the plate of ground glass, so as to shade the latter from the light; sides are sometimes provided to exclude the lateral light; which may also be accomplished by throwing a dark-coloured cloth over the box.

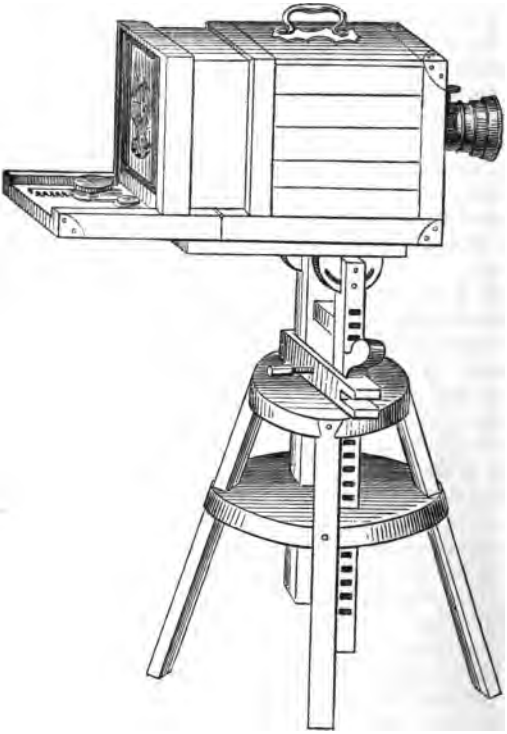
The rays which produce the picture, entering through the lens B, fall upon the mirror M, by which they are reflected upwards, to the plate of ground glass N, on which they produce the picture. The instrument is brought into focus by drawing out the end O of the box, until the picture appears with sufficient distinctness on the glass N.

A leaf of tracing paper, being laid upon the glass, the picture is seen through it, so that it can be traced with facility and precision.

7. The form of camera usually employed for photography is represented in fig. 5; it is more simple in its construction than those already described, neither the prism nor the oblique mirror being used. The convex lens, or its optical equivalent, is set in a tube at one end of a square box, in which another square box slides like a drawer; in the end of this last, a plate of ground glass is let in, by means of grooves, so that it can be inserted and removed at pleasure; the instrument is brought into focus, either by sliding the one box within the other, or by a rack and pinion in the groove. When the picture is distinctly delineated upon the ground glass, the latter is drawn out, and a case containing the daguerreotype-plate or photographic-paper is inserted in its place. The paper or plate being, in the first instance, screened from the reception of the picture by a plate of metal or board let into a groove in front of it. When all is prepared for the operation, this screen is suddenly raised by the operator, and the picture allowed to fall upon the prepared paper or plate, and being allowed to continue there a certain number of seconds, more or less according to the brightness of the light, the screen is again suddenly let down, and the case containing the paper or plate is withdrawn from the groove, and the paper or plate is submitted to certain chemical processes by which the picture is brought out and rendered permanent.

The cameras which are adapted to photography require to be constructed with greater attention to optical precision than those which are used for other purposes in the arts. The focal length of the lenses being much shorter, optical expedients must be adopted for the removal of spherical aberration, which are not necessary in other applications of the instrument. The nature of photography also renders it necessary that the lenses should be achromatic or nearly so. These conditions, as well as the chemical processes by which the daguerreotype-plate or photographic-paper is prepared before receiving the picture, and treated after its reception, will be more fully explained in another Tract of this series, which will be expressly devoted to Photography.

Fig. 5.



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